UNIVERSITY OF SOUTHAMPTON

FACULTY OF LAW, ARTS AND SOCIAL SCIENCES

School of Arts

Eero Aarnio's *Globe*: A Platform for an Investigation of Challenges and Possibilities Related to the Conservation of Twentieth Century Foam Upholstered Furniture

by

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ABSTRACT

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EERO AARNIO'S GLOBE: A PLATFORM FOR AN INVESTIGATION OF CHALLENGES AND POSSIBILITIES RELATED TO THE CONSERVATION OF TWENTIETH CENTURY FOAM UPHOLSTERED FURNITURE

by Joelle Del'Orme Juers Wickens

This thesis focuses on the conservation challenges posed by the *Globe*, a foam upholstered chair designed by Eero Aarnio (Finnish, b. 1932) in 1963 and purchased by the Victoria and Albert Museum in 1968. It introduces the challenges of preserving this particular *Ball* chair, an icon of modernism, through a detailed object record and condition report, which was prepared by integrating information from a wide range of primary and secondary sources. Five possible approaches to the physical conservation of the *Globe*, and 20th century foam upholstered furniture in general, are identified and evaluated. Significance assessment (including analysis of the role of the chair in the V & A's collection) led to a conservation recommendation that, if possible, the chair's original wool top cover and original polyether polyurethane foam upholstery padding be re-adhered. The rationale, methodology and results of a unique series of laboratory tests (peel and stress rupture tests, plus artificial ageing), designed to test the viability of the recommendation and carried out on 475 samples of naturally aged upholstery foam and fabric from a 1960s *Ball* chair, are presented. The tests results indicated that a new technical conservation solution for the *Globe* had been identified which would make it possible to re-adhere the original top cover to the original upholstery foam in a conservation appropriate way while retaining the original polychloroprene based upholstery adhesive. The solution is sensitive to the ethos of modernism, which depended on an alliance of design, materials and technology. It is likely to be useful in developing conservation techniques for other foam upholstered furniture. The theory at its foundation may be meaningful for the conservation of 20th and 21st century artefacts as a whole.

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Declaration of Authorship

I, Joelle Del'Orme Juers Wickens

declare that this thesis entitled

Eero Aarnio's *Globe*: A Platform for an Investigation of Challenges and Possibilities Related to the Conservation of Twentieth Century Foam Upholstered Furniture

and the work presented in the thesis are both my own, and have been generated by me as the result of my own original research. I confirm that:

- this work was done wholly or mainly while in candidature for a research degree at this University;
- where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated;
- where I have consulted the published work of others, this is always clearly attributed;
- where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work;
- I have acknowledged all main sources of help;
- where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself;
- none of this work has been published before submission.

Signed:..[redacted]......................................

Date:............19....December....2007.................................

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List of Abbreviations

°C	degrees Celsius
2CM	20th Century Marks
AIC	American Institute for Conservation of Historic and Artistic Works
AICCM	Australian Institute for the Conservation of Cultural Material
ATR	attenuated total reflectance
Beva	Beva® 371 Film
BSI	British Standards Institution
c.	circa
CCI	Canadian Conservation Institute
cm	centimetre
EH	English Heritage
FTIR	Fourier Transform Infra-red Spectroscopy
g	gram
GCI	Getty Conservation Institute
ICOM	International Council of Museums
IIC	International Institute for Conservation of Historic and Artistic Works
Impranil	Impranil® DLV Dispersion
JAIC	Journal of the American Institute for Conservation
kg	kilogram
l	litre
Lascaux	Lascaux Acrylic Adhesive 360 HV
LACMA	Los Angeles County Museum of Art
LTM	London Transport Museum
m	metre
MFA	Museum of Fine Arts
min	minute
µm	micrometre (micron)
mm	millimetre
ml	millilitre
MMFA	Montreal Museum of Fine Arts

MoMA	Museum of Modern Art
N	Newtons
n.d.	no date
NT	National Trust
Plextol	Plextol® B-500
Primal	Primal B-60
RH	Relative humidity
s	second
SSCR	Scottish Society for Conservation and Restoration of Historic and Artistic Works
TCC	Textile Conservation Centre
TDI	Toluene diisocyanate
UK	United Kingdom
UKIC	United Kingdom Institute of Conservation
V & A	Victoria and Albert Museum
VDM	Vitra Design Museum
w/v	weight/volume
WAAC	Western Association for Art Conservation

Preface

This thesis is one result of a project which set out to uncover information which would be of use to conservators currently working in the field of upholstery conservation. It sought to find a technical solution to a current conservation challenge as defined by them.[1] At the same time the intention was to define the search for a solution in a way which would make the process and results valid in the eyes of furniture and textile historians and conservation scientists. This was considered paramount as individuals from these fields of practice are often involved in the decision making process which ultimately decides how an upholstered object will be conserved. This thesis seeks to balance the presentation of the details of the project in a way that will make it accessible and relevant to conservators, historians and scientists alike. As a result certain aspects of it will be found to be more general, more basic or more specific than any one of these individuals might require or desire. As a whole however, it is hoped that the project and the thesis will introduce, clarify and expand upon some of the issues and challenges faced by each of these groups of people when considering how an upholstered object might be conserved. In turn it is hoped the information will influence the design and execution of future research projects making the results even more relevant to all involved.

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[1] An informal survey of curators and conservators in Europe and North America and a detailed literature search of upholstery conservation literature published in the English language were used as the primary sources when defining the challenge. The individuals who participated in the survey along with the institutions they represented at the time the survey was carried out are listed in Appendix 1. The documents consulted during the literature search are recorded in the bibliography of this document.

Introduction – A Reason, the Challenge, a Problem in the *Globe*, the Possibilities

A reason to conserve historic objects

> What matters is that the objects they use should survive.
>
> Why is this survival so important? Why preserve the things that have passed? Do we care what Tyrannosaurus looked like? Do paintings and sculpture touch our lives? Does it really matter that our children hear the creak of a wooden ship?
>
> It does matter because these are the memories of our human progress. The future is void, and the present, a fleeting reality that slips instantly into the past. Our heritage is all that we know of ourselves: what we preserve of it, our only record. That record is our beacon in the darkness of time; the light that guides our steps. Conservation is the means by which we preserve it. Like the museum itself, it is a commitment not to the past, but to the future. (Ward 1986: 64-65)

The research described in the following pages was built on the foundation that preserving memories of human progress[2] is an activity worthy of pursuit and efforts which seek to develop new methods of preservation represent time well spent. This point will not be argued or justified. It must simply be accepted. What does not require simple acceptance is the fact that the selection of objects worthy of preservation or the method by which these selected objects should be preserved is straightforward.

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[2] The word progress is used here as it was Ward's choice of word. However it is the author's belief that the word journey is more appropriate. Progress implies moving forward or advancing. Journey implies more simple movement. Women obtaining the right to vote in any particular organization, municipality or country would be seen as progress by some and much less than that by others but whether it is seen as progress or not the event, each time it happens, is part of the journey of the human race. If the goal is to preserve evidence of human progress then the question of whose progress becomes important. If the goal is to preserve evidence of the human journey all events qualify.

The challenge of determining what is best

The Canadian Museum of Civilization, Gatineau, Canada has built a collection of consumer goods from the second half of the twentieth century, which includes canned and bottled food. Some of these goods are perishing or have perished quite quickly. In order to preserve these objects in part, original seals on the bottles were broken and holes were drilled into the cans in order to remove the food they contained – sacrificing part of the object in order to preserve another. When considering these objects some accept this approach as appropriate conservation, others question a conservation approach that removes original material from an object even if it is not in its original state, others question 'damaging' one part of an object to preserve another and still others take the questioning further back, to the original collecting policy, wondering whether it was in the collecting and not in the subsequent conservation that an error in judgement was perhaps made.[3]

An album of personal mementos compiled by Caroline Légaré Cinq-Mars (1822-1913) was acquired by the Library and Archives Canada in 1977. The album contained among many other things, extremely fragile and degraded botanical specimens – dried and pressed flowers, leaves and butterfly wings. In order to preserve these specimens they were sprayed with an approximately 1 micrometre (μm) thick layer of the consolidant, Parylene C. In the opinion of those responsible for the conservation, the treatment safely strengthened the specimens in an unobtrusive and controlled manner but at the same time applied a layer of consolidant which can never be removed. As this application permanently alters the physical characteristics of the specimens some people practising in the heritage preservation profession find it unacceptable. For others, the unobtrusive addition of a material which preserves something which without intervention might not last until tomorrow is a perfectly reasonable conservation approach.[4]

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[3] Information recorded by the author at the Canadian Association for Conservation Workshop, 26-27 May 2004, *Unusual Materials, Unconventional Treatments* during the presentation, Is there a future for our recent past? Determining procedures for collecting and caring for 20th century artefacts at the Canadian Museum of Civilization, given by Paul Robertson, Curator, and Martha Segal, Conservator, at the Canadian Museum of Civilization, Gatineau

[4] Information recorded by the author at the Canadian Association for Conservation 30th Annual Conference, 28-30 May 2004 during the presentation, The Caroline Légaré Cinq-Mars Album, given by Frida Kalbfleisch and Wanda McWilliams, of the Library and Archives Canada, Gatineau.

In June 2000, *Un Dictionaire*, a series of 225 enlarged and embellished newspaper clippings by Melvin Charney, were to be exhibited in the Canadian pavilion at the VIIth International Architecture Biennale in Venice. The pavilion was humid, with dirt and insect levels which were impossible to control. During past exhibitions objects had been damaged by mould, buckling and rust. In consultation with the artist, it was decided to display laser photocopies of the original images rather than the originals themselves. The artist agreed to this approach because he felt the viewer would not be able to tell the difference. Curators and conservators agreed because the solution allowed the mounting of the requested exhibition but protected the original artworks from sure destruction. For many who believe it is the image in any accurately reproduced form that constitutes art this compromise seems reasonable. Others feel that this approach embodies deception and is a compromise which has been taken too far.[5]

In these three cases and hundreds and thousands more like them, coming to a decision regarding the most appropriate conservation approach would not have been a simple, straightforward journey. The final road taken would have left some in doubt that the right choices were made. Others would have been convinced the process was successful. Others would definitely have made different choices given the opportunity. The American Institute for Conservation of Historic & Artistic Works (AIC) has the *AIC Code of Ethics and Guidelines for Practice* (AIC 1994). The International Council of Museums (ICOM) has the *ICOM Code of Ethics for Museums* (ICOM 2006). The Australian Institute for the Conservation of Cultural Material (AICCM) has the *AICCM Code of Ethics and Code of Practice* (AICCM 2002). These codes and those of many other small and large conservation organizations are in part meant to guide conservators and others as they make the decisions which influence treatment choices like those above. However, none of these codes provide a step by step solution for even the simplest of conservation treatments. The process involves gathering information, considering what choices could be made, weighing the pros and cons of various options and eventually coming to a decision. When undertaken with extreme care the end result is generally a well considered solution and the 'best' solution given a specific set of circumstances. It is often likely that in years to come, with the benefit of hindsight and

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[5] Information recorded by the author at the Canadian Association for Conservation Workshop, 26-27 May 2004, *Unusual Materials, Unconventional Treatments* during the presentation, Reproductions as art or proxy? Preparing Melvin Charney's 'Un Dictionaire... Illuminations, 1970-2000' for exhibition at the Venice Architectural Biennale, 2000, given by Claire Titus, conservator in private practice

more knowledge, a different, ‘better’ choice will become clear. It is certainly possible that such would be the case for the following object but what if it is considered today?

A problem in the *Globe*

The *Globe* (Circ. 12-1969) is a foam upholstered chair from the 1960s currently in the care of the Victoria and Albert Museum (V & A), London (Figure 1). It was designed by Eero Aarnio (Finnish, b. 1932) in 1963 and introduced to the international furniture market at the Cologne Furniture Fair in 1966. In 1968 the V & A purchased the *Globe* direct from the manufacturer, Asko, with the intention of including it in 'Modern Chairs, 1918-1970: an international exhibition presented by Whitechapel Art Gallery in association with the Observer and arranged by the Circulation Department, Victoria & Albert Museum'.[6] When the chair arrived at the museum it would have looked much like it does in Figure 1. By May 2004, even though it had only ever been used and displayed in a museum environment, it appeared as seen in Figure 2. An initial examination of the chair left the reasons for its degradation unclear. It left open an original assumption that the foam beneath the top cover was probably weakened and beginning to crumble causing the fabric to separate from it. It left no doubt that the conservation of the chair would have to consider what to do with the flexible foam beneath the sagging woven top cover and the sagging woven top cover itself.

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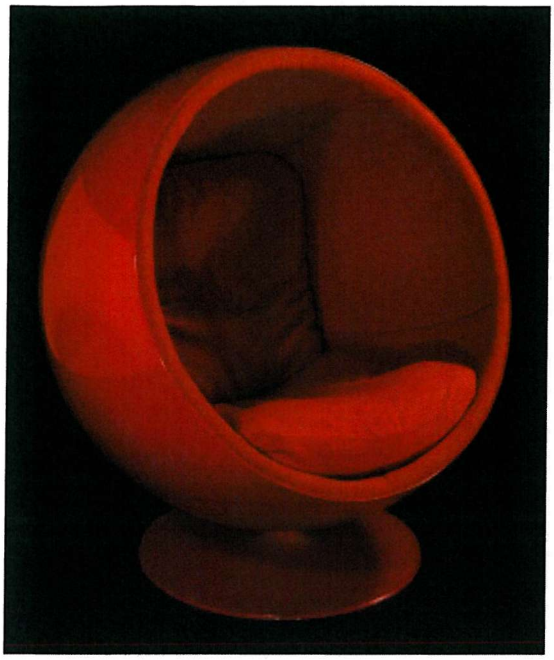
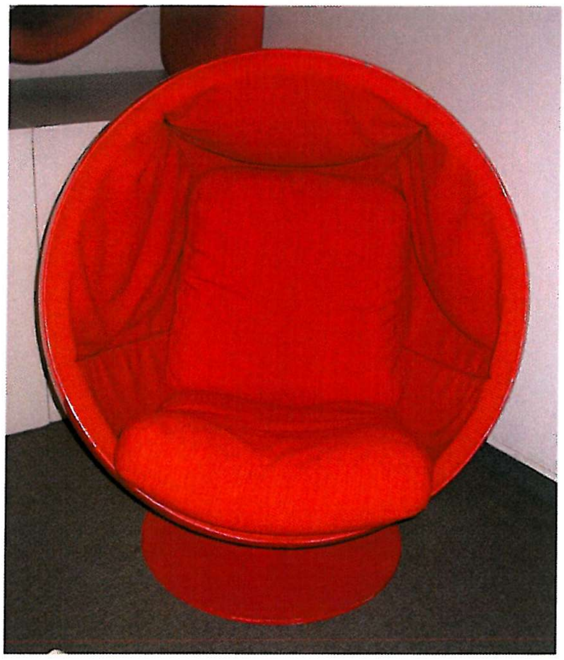
[6] Details from V & A file, Asko, Messrs. MA/1/A1003



▲ Figure 1: The *Globe* chair on 13 May 1986, before obvious degradation set in. V & A - Circ. 12-1969 (Photo – V & A Images)



▲Figure 2: The *Globe* chair on 12 May 2004, showing visual signs of degradation in the sagging top cover. V & A - Circ. 12-1969 (Photo – J. Wickens)

The conservation solutions represented in the vignettes above suggest three of the paths which might be taken if the chair were to be conserved today. Like the food in the consumer goods collection, original seals (in the form of stitching or adhesive bonds) could be released in order to remove the foam which was originally used to upholster the chair. Some would argue that foam is such a rapidly degrading material that any effort to conserve it would not be worthwhile. If it was removed a small, concealed, relatively insignificant part of the chair would be sacrificed in order to better preserve the rest of the object. Others might argue that leaving the foam in place and coating it with a consolidant in order to stabilize and strengthen it would be a better approach. The foam is original to the chair and even though the application of a consolidant might alter some of its physical characteristics such a process might make it possible to leave it in place in the chair. Others could argue that because the chair is still being manufactured today the quickest and perhaps least expensive solution would be to replace it with a new one. The visual impact of the chair would be 'restored' in this new object and the old one could be moved to storage or discarded as appropriate.

For curators and conservators responsible for the care of twentieth and twenty-first century foam upholstered objects this brief summary of the *Globe* might be best described as the tip of a cracking, crumbling, splitting iceberg. This would also be true for the design museums, modern art museums, historic houses, transport museums and decorative art museums wanting to display them. It is so for the twentieth century furniture dealers trying to preserve both their function and value. Even at least one art insurance company would be likely to accept such an analogy as it looks for ways to restore what it sees as currently unsalvageable works of art (Albus et al 2007).

At the Vitra Design Museum (VDM), Weil am Rhein, Germany there is a possible prototype, circa (c.) 1959, (MPA-1012) for the *Cone* chair by Vernor Panton (Figures 3 & 4). The foam beneath the top cover has become hard and rigid but the chair itself has not yet lost most of its shape. Should the foam be removed and replaced with something more stable? In order to remove the foam original elements of construction would need to be released to temporarily remove the top cover. Is such a release acceptable? Although having spent hours in discussion regarding these issues personnel at the museum could not decide.[7] At the Museum of Fine Arts (MFA), Boston, there is an *Egg* chair and ottoman by Arne Jacobsen which was designed in 1957 and manufactured in 1963. In this chair the foam beneath the top cover has also degraded. If lightly touched it permanently loses its shape and evidence of a sagging profile can now be seen (Figure 5).[8] A similar situation is presented by a George Nelson *Coconut* chair, c. 1955, (MUS-1066/2) at the VDM where visible signs of profile change are starting to appear. However in this case the foam appears to be expanding rather than crumbling away (Figure 6).[9] Should these early signs of profile change signal an immediate identification as a conservation priority in order to stabilize the chairs? Are they an indication the chairs are already 'lost causes'? Are they nothing to worry about at this stage in the ageing process? In other cases the signs of degradation are far from invisible or just barely visible. At its Fort Brockhurst storage facility English Heritage (EH) maintains a *Ministry of Defence Armchair* of an unidentified date. The chair

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[7] Personal email communication with Kathrin Kessler, Conservator, AXA Art Conservation Project in cooperation with the VDM, 18 March 2004 and personal visit to the VDM, 4-6 April 2005. Fiell & Fiell (2002) date the Cone Chair to 1958 and the VDM dates the possible prototype as 1959 which places the relationship in doubt but does not change the problem presented by the degrading foam.

[8] Personal email communication from Angela Meincke, Assistant Conservator, Museum of Fine Arts, Boston on 19 April 2005

[9] Personal visit to the VDM, 4-6 April 2005

contains foam which has expanded and hardened so much the top cover fabric could not be re-secured around it without cutting away some of the foam (Figures 7 & 8).[10] At the London Transport Museum (LTM) the same situation presents itself with seats on a 1931 *Trolley Bus*. In this same bus there is also the problem of seats having suffered the reverse. The upholstery foam has become compressed and crumbled and the profile of the seats now sags significantly (Figure 9).[11] Should the profiles of these objects be restored and if so is the cutting away or complete removal of the foam an acceptable approach to the process?

▲Figure 3: Possible prototype c. 1959 for the *Cone* chair by Vernor Panton. The foam beneath the top cover is hard but the chair retains its shape. VDM - MPA-1012 (Photo – J. Wickens)

▲Figure 4: The *Cone* chair, designed by Vernor Panton, c. 1958. The chair for which that in Figure 4 is a possible prototype although the attributed dates for each leaves this in question. (Photo – Fiell & Fiell 2002: 120)

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[10] Personal visit to the English Heritage Fort Brockhurst storage facility, 29 July 2004

[11] Personal visit to the London Transport Museum Depot and conversation with Bob Bird, Senior Curator of 3D Collections, 9 March 2004

▲ **Figure 5: The *Egg* chair and ottoman, designed by Arne Jacobsen c. 1957, manufactured in 1963. Note the rippled fabric just above the seat cushion. MFA, Boston – no catalogue number (Photo - MFA)**

▲ **Figure 6: The *Coconut* chair, designed by George Nelson, c. 1955. Note the raised areas in the profile on the proper left edge and at the upper most point. VDM - MUS-1066/2 (Photo – J. Wickens)**

▲**Figure 7: A Ministry of Defence armchair, English Heritage collection in storage at Fort Brockhurst. The foam in the armrests is expanding and distorting the profile. EH – no catalogue number (Photo – J. Wickens)**

▲**Figure 8: A Ministry of Defence armchair, English Heritage collection in storage at Fort Brockhurst. Detail of proper right armrest in Figure 7 showing expanded foam. EH – no catalogue number (Photo – J. Wickens)**

◄ Figure 9: A rear seat on the upper deck of a 1931 trolley bus at the London Transport Museum Depot. Note the sagging profile of the seat. LTM – no catalogue number (Photo – J. Wickens)

Like the *Globe*, the conservation of each of these objects raises questions as to what to do with the degrading foam in each one of them. Should it be removed? If it is with what should it be replaced? Should it be consolidated and left in place? If it is will it eventually cause damage to the materials and objects surrounding it? Can a replica or a new object be used in its place so the issue of the degraded foam can be cast aside? If a replica is not used and one of the first two options is pursued is it appropriate to temporarily remove the original top cover on a chair and in the process sever original stitching or an original adhesive bond in order to do so? If the fabric is removed will it be able to be reapplied?

There are other chairs in which although the presence of foam is not so obvious it is still causing problems. The top cover fabric in a privately owned chair possibly designed by Robin Day was in all likelihood originally secured to the hard chair shell with a thin layer of foam. That foam has now almost completely degraded and all that remains is a brown, crusty residue. In so doing it has apparently lost its ability to secure the fabric to the chair and the fabric is now falling away from significant portions of the outer surface (Figures 10 & 11).[12] At the VDM there is a different example. Gaetano Pesce designed the *Sit Down* chair in 1975-1976. It has a quilted cover which acted as a mould for the polyurethane foam that was poured into it (Fiell & Fiell 1997). The cover of the *Sit Down* chair at the VDM has become soiled and it is splitting but there is no obvious

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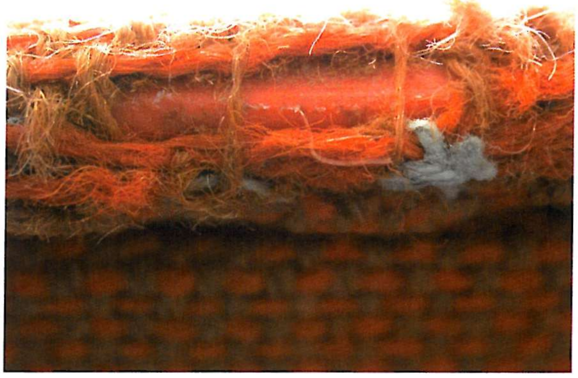
[12] Personal examination of the chair in question at the Textile Conservation Centre, 16 February 2004

way to remove it due to the way the fabric becomes secured to the foam in the manufacturing process (Figure 12).[13]

▲Figure 10: Chair possibly designed by Robin Day – note the top cover falling away from the chair structure on the proper left – privately owned (Photo – J. Wickens)



▲Figure 11: Chair possibly designed by Robin Day – detail with brown, crusty foam residue just visible between the fabric and chair shell – privately owned (Photo – J. Wickens)

◄ Figure 12: *Sit Down* chair, designed by Gaetano Pesce, c. 1975-76 – note the soiled, splitting top cover which has been moulded to the underlying foam – VDM – no catalogue number (Photo – J. Wickens)

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[13] Personal visit to the VDM, 4-6 April 2005 and email communications with Kathrin Kessler, Conservator, AXA Art Conservation Project in cooperation with the Vitra Design Museum, 18 March – 26 July 2004

And in one more variation on a theme, there are objects containing as yet relatively undegraded foam which are still causing problems. At Homewood, a 1930s property in Surrey recently acquired by the National Trust (NT), foam upholstered furniture currently on display contravenes fire regulations. The Trust is considering the possibility of removing and replacing the foam in these pieces of seat furniture in order to be able to keep them on display.[14]

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[14] Personal email communication from Frances Lennard, Textile Conservation Centre on 27 September 2004

The problems which offer possibilities for a solution

Foams are however not only a problem for those responsible for the care and display of upholstered furniture. They have been used in the manufacture of fabrics subsequently used in the design and manufacture of 1960s dresses. Some of these dresses are now shadows of their former selves due to the degrading foam in them (Lovett & Eastop 2004). Foams have been used in the creation of TV puppets. Some of these puppets are still in an apparently stable condition. Others are falling apart (Keneghan 1996; Smith 2004). Perhaps most thankfully foams have been used in the creation of twentieth and twenty-first century art. In these pieces, unlike the upholstered pieces described above where the foam is concealed beneath top cover fabrics, the foam is often the primary substance from which the object is made. As the foam cracks, crumbles, splits and expands the surface of the object changes colour, shape and its general character. Eventually the entire object may turn to powder and dust. As some of these objects literally disappear before the eyes of those entrusted with their care a greater urgency with respect to how to conserve them and prolong their lives appears to have developed. This has led to investigations regarding specific techniques which might be used to conserve them. As it will be shown, in these techniques lies a foundation for a possible conservation solution for the *Globe* and perhaps in a solution for the *Globe* lie ideas for solutions for other foam upholstered objects.

Chapter 1 – The *Globe* and *Balls*: Their History, Construction and Condition

A detailed study of the history, construction and condition of the Globe was carried out in order to provide a document of the chair as it existed in 2004. That document is presented here providing a record of the chair prior to any known alteration by human hands. The establishment of a record was not however the only purpose of the study. The study and this record provide an introduction to the place of the Globe in history. This information in turn offers at least an indication of why the object is worthy of preservation. The record serves as a tool for understanding the physical constraints the construction of the Globe would place on a conservation project. It details how the chair has changed with the passage of time and therefore part of what would need to be addressed if the chair was to be conserved.

The study was necessary because no record of all of the required information existed. It is true the chair is less than 40 years old and still being produced but even so, no record of its production and how the process has changed with time was available. In order to gather the required information the Globe and archival evidence connected to it were examined in detail. Other Ball chairs and numerous images of them were scrutinized. Those producing, selling and caring for the chairs were contacted. Secondary sources making reference to Ball chairs were consulted. The end result was a very specific understanding of the Globe and its history, construction and condition and a more broad understanding of the same three aspects of Ball chairs in general. Each aspect is presented in this chapter first with reference to the Globe then with reference to the general class of Ball chairs.

1.1 - History of the *Globe*

A red *Globe* was purchased by Mr. Carol Hogben, Deputy Keeper of Circulation at the V & A in 1968 for the price of £106.80[15] along with a yellow *Pastil*[16] chair, c. 1968, also designed by Eero Aarnio and manufactured and marketed by Asko. They arrived at the museum in two separate crates[17] on 10 February 1969 and both were intended to be included in the travelling exhibition, 'Modern Chairs, 1918-1970: an international exhibition presented by Whitechapel Art Gallery in association with The Observer and

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[15] At the time the current retail price was £280.

[16] Museum catalogue number, Circ. 13-1969; Cost £20.80 (retail price £49.00)

[17] It is recorded that part of the inspiration for the *Pastil* was to create a chair which could be shipped inside the *Ball* and the dimensions of the chair where defined by this plan (Adelta n.d.). It is therefore interesting to note that the chairs arrived in separate crates.

arranged by the Circulation Department, Victoria & Albert Museum'.[18] However, only the *Pastil* is listed as a numbered item in the exhibition catalogue, leaving open the possibility that the *Globe* was not ultimately included in the exhibition (Whitechapel Art Gallery 1970).

The initial description of the chair registered by the circulation department lists the chair as the '*Globe*'. Presumably this title of *Globe* was assigned as the same word is on the original invoice for the chair, provided by Asko. However, throughout history these chairs are more commonly referred to as *Ball* chairs. Therefore, when referring to the specific chair at the V & A the word *Globe* will be used. *Ball* will be used in all other instances.[19]

Little else of the specific history of the chair is clear. Sometime prior to December 2002 it was moved to the Twentieth Century Study Galleries at the V & A. In May and December 2004 it was still displayed there but in the following year it was removed from the galleries due to the renovation and reassignment of the use of the gallery space. In 2007 it was in the care of the V & A's furniture conservation department as it was being prepared for an exhibition scheduled to open at the museum in autumn 2008.

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[18] Details from V & A file, Asko, Messrs. MA/1/A1003

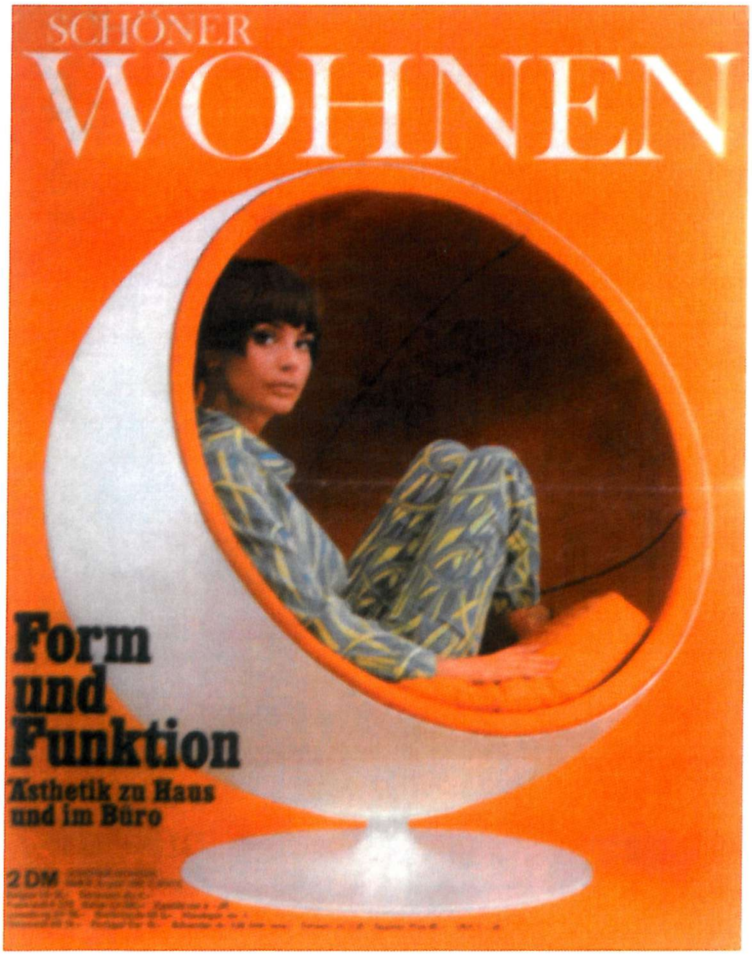
[19] Details from V & A file, Asko, Messrs. MA/1/A1003

1.2 – History of the *Ball* chair

The details of the creation, introduction and subsequent impact of the *Ball* chair, in general, are known in much more detail. The *Ball* was designed by Aarnio in 1963. In that year he, his wife and two daughters moved into a four room flat in Helsinki, Finland. Having very little money and no large, comfortable furniture with which to fill the flat, Aarnio set about designing his own with his first goal being a big chair with a bold new look. That chair became reality beginning with a series of sketches that were simplified over and over again until a final drawing of something based on a perfect sphere was produced. The dimensions of the sphere shaped object were established when Aarnio pinned the sketch to the wall and asked his wife to mark the position of his head and the length of his shin as he sat in front of it. The initial details suggesting that the chair shell could be made of fiberglass but would need to be reinforced with metal rods were worked out with the building of a full scale prototype. Finally, with the launch of the chair by the Asko Furniture Company at the 1966 Cologne Furniture Fair (Figure 13), Aarnio's vision became something others could buy (Aarnio 2003; Adelta n.d.).

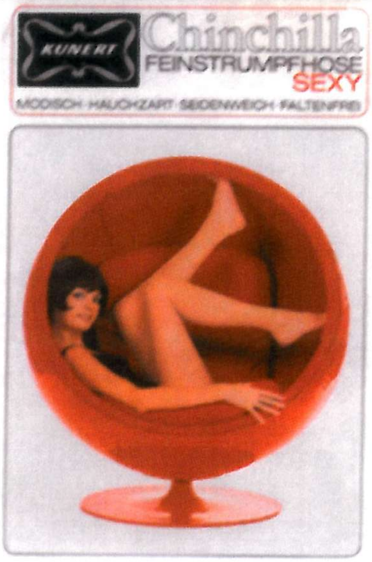
◄ Figure 13: An image of the *Ball* Chair being introduced at the Cologne Furniture Fair, 1966. (Photo – Kalha 2003: 88)

Following its introduction it was almost immediately used as a marketing image on magazine covers (Figure 14), product packaging (Figure 15) and in the shop window of designer Mary Quant's London boutique (Watson 2002). By 1969 it had found its way onto the silver screen in Paramount Pictures Corporation's *The Italian Job* (Watson 2002). It was being used as an image of power and evil in the BBC TV series *The Prisoner* (Figure 16). Since then it has graced the covers of books about furniture, *Chairs* (Fiell & Fiell 2002) and *Op to Pop: Furniture of the 1960s* (Greenberg 1999), been used in a greeting card design (Figure 17) and been installed as functional items in Mudd Library, Oberlin College, Oberlin, Ohio, USA (Figure 18). Today it is still used as a marketing image in magazines and on the internet (Figure 19). It is used as an image to portray youth and vitality as it exists in the present and as evidence that it existed for someone in the past (Figures 20 & 21).



◄ Figure 14: The August 1966 cover of the magazine *Schöner Wohnen.* (Photo – Kalha 2003: 74)

▼ Figure 15: A 1960s label for *Kunert* panty hose. (Photo – Kalha 2003: 75)



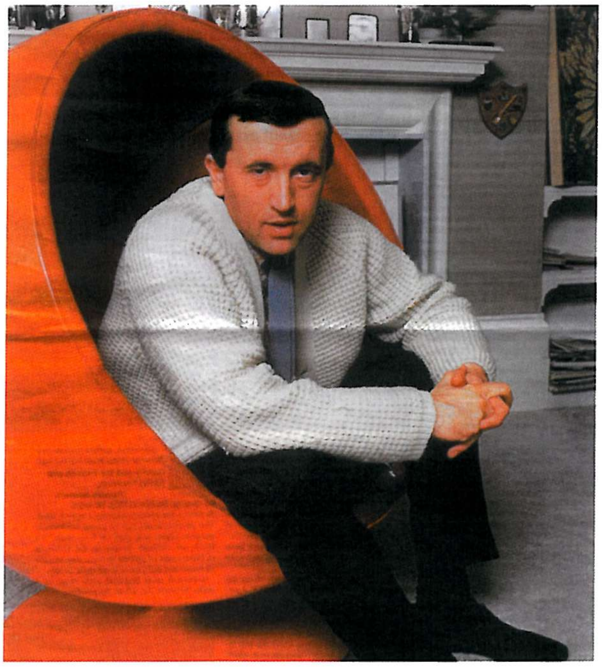
◄ Figure 16: The evil villain, Number Two, from the 1960s BBC TV series *The Prisoner*, sitting in a version of the *Ball* chair. (Photo – www.the_prisoner/info)

◄ Figure 17: The front of *Relax,* a greeting card by Nouvelles Images.

▼ Figure 18: Three *Ball* chairs at Mudd Library, Oberlin College, Oberlin, Ohio, USA. (Photo - www.oberlin.edu/gaws/research)

◄ Figure 19: A marketing image for Skyy Vodka used in Time Magazine, May 2007 and on the Skyy Vodka website in September 2007. (Photo – www.skyy.com)

▼ Figure 20: A 1960s image of Sir David Frost, 'the epitome of Sixties groove'. (Photo - *Daily Mail*, 4 June 2005)



▼ Figure 21: The image accompanying an article about a terminally ill teenager who stops medical treatment in order to enjoy what life she has left. (Photo - *Metro*, 7 December 2006, with credit to NNP)

Brave: Leukaemia patient Josie Grove wants to enjoy her life rather than continue treatment

It was originally manufactured and distributed by Asko from 1966 to c. 1980, with the end of fabrication brought on by the rising cost of plastic production, a direct result of the rising price of oil (Aarnio 2003; Korvenmaa 2003; Sparke 1986). In 1992 it was reintroduced by ADELTA and in 2007 is still being manufactured and marketed by them (Adelta n.d.; Fiell & Fiell 2002: 23). Throughout this entire production history it has been manufactured in the same Finnish factory using the same moulds with which Asko began the process.[20] At different times the final stages of production have included fitting the chairs with telephones, speakers and internet connections (Kalha 2003; Tanninen-Mattila 2003).

Its significance, impact and connections to societal trends have been subjects worthy of time and written thought for some historians. It has been offered that the *Ball* is 'a response to the quest for a self-contained environment, a post-Freudian upholstered "womb"' (Eidelberg 1991: 316). Greenberg (1999: 22) discusses the influence of space travel on furniture design saying that a growing 'awareness of ourselves as a planet afloat in the cosmos' defined the sphere as the most characteristic shape of the 1960s. In using it in the creation of the *Ball*, Eero Aarnio might not have actually sent a man into space but he provided 'a personal space capsule, outfitted with stereo speakers, in which to take solitary flight'. More generally, Aarnio's chairs have been labelled as being an 'inextricable part of Finnish identity' (Tanninen-Mattila 2003: 9). They have been said to represent technical innovation, faith in progress, youthfulness and the pursuit of gratification (Sarantola-Weiss 2003).

The *Ball* is known to exist currently in collections at the V & A, the Montreal Museum of Fine Arts (MMFA), the VDM, the Design Museum (London), and the Powerhouse Museum (Sydney). It has been included in a variety of exhibitions including *Contemporary Chairs* at the Musée des Arts Décoratifs, Paris in 1968, *That's It! The Design of Eero Aarnio* at Galeria da Árvore, Porto in 2001, *Eero Aarnio* at the Kunsthalle Helsinki in 2003 and *Pop Fantasies: Furniture Design by Eero Aarnio* at the Finnish embassy, Washington, DC in 2005 (Barbosa & Guimarães 2001; Hales 2005; Sarantola-Weiss 2003; Watson 2002).

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[20] Personal conversation with Bert Ufermann, managing director of ADELTA, 29 April 2004

In short, since its introduction in 1966, the *Ball* has been used as a chair but also as an image which has impact. It has sparked the opinions of historians and been identified as an object worthy of museum space and funds. If a willingness to purchase something marks it as significant then the purchase by the V & A in 1968 sets an early marker, a 2005 auction bid by the National Gallery of Victoria sets a much more recent one.[21] The acquisition by Grace Kelly and Sammy Davis, Jr., among others, in its early years marked it as a must have object (Hales 2005). The 2005 purchase of an early *Ball* at a Sotheby's London auction marks it as collectible today.[22] The fact that on 9 August 2007 one could be purchased online from numerous retailers including, www.designshopuk.com for £3,750.00, marks it as a currently desirable new item in contemporary society.

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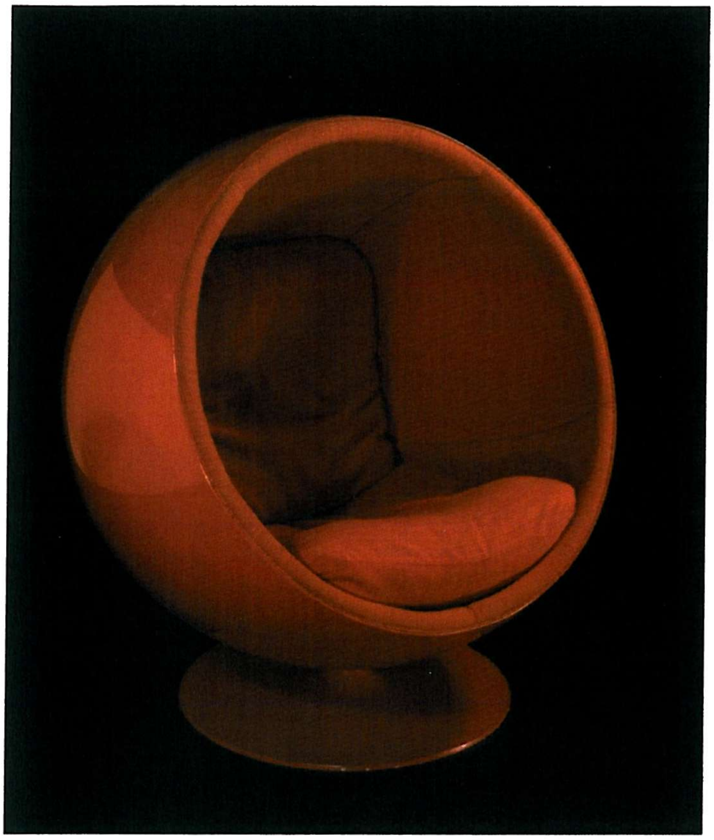
[21] Personal email communication from Holly McGowan-Jackson, Senior Conservator of Frames & Furniture, National Gallery of Victoria, Melbourne, 29 April 2005

[22] Details available at http://www.sothebys.com/app/live/lot/LotDetail.jsp?sale_number=L05814&live_lot_id=146

1.3 – Construction of the *Globe*[23]

In its simplest form, the *Globe* is a fibreglass shell with a foam upholstered interior which is mounted on a metal pedestal. The shell has been stabilized with four metal rods and the chair has been finished off with two loose box cushions (Figure 22).



◄ **Figure 22: The *Globe*, a fibreglass shell with a foam upholstered interior. V & A - Circ. 12-1969 (Photo – V & A Images)**

1.3.1 – The shell

The shell is a hollow sphere which has had one face cut off in a nearly vertical direction. The outer layer of the sphere is constructed with a red, smooth layer of gel coat(?)[24]. In the gel coat there is an approximately 2 millimetres (mm) high ridge which runs along the circumference of the shell, beginning and ending at the centre top and bottom of the sphere opening. The ridge is a by-product of the manufacturing process and its existence

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[23] The details for this section were gathered during two separate examinations of the *Globe*. The first took place in the Twentieth Century Study Galleries on 12 May 2004 and the second in the V & A Textile Conservation Studio on 14-16 December 2004.

[24] All materials identification which was not confirmed by analysis is indicated with a question mark in parenthesis, represented thus (?).

is evidence that the chair has not been recoated.[25] Additionally, a label similar to that drawn in Figure 23 has been moulded in the gel coat. The top proper right corner of the label is located 103 mm down from the lower edge of the shell and 23 mm to the proper left of the ridge just described. Figure 26, Page 25 marks its approximate location. The inner layer of the shell has been constructed with non-woven(?) fibreglass(?) in an apparently unpigmented cream shade.

◄ **Figure 23: A rendering of the Asko label moulded into the gel coat at the base of the *Globe*. The line of question marks in the text at the bottom of the label represents an illegible word which is written in script typeface.**

This two layered structure has been reinforced with four metal rods located as in Figure 24. The circular rod located at the opening of the sphere is set back from the edge by approximately 60 mm. The rod which runs from top edge to bottom edge mirrors the location of the ridge in the gel coat on the outer surface. The intersection of the criss-crossing rods at the bottom of the sphere is located 410 mm back from the bottom edge. The exact length of these criss-crossing supports can not be determined as they are obscured by the chair's upholstery. The rods have been covered with woven fibreglass(?) in all areas where visual examination of them was possible.

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[25] Personal conversation with Michael Marks, owner of 20th Century Marks, a twentieth century furniture resale establishment in Essex, England, 20 August 2004

◄ Figure 24: The black lines indicate the approximate location of the stabilizing bars detailed in the previous text. VDM – SSK-1002 (Photo: J. Wickens)

1.3.2 – The pedestal

At the location where the supports described above criss-cross, the sphere is mounted on a circular metal(?) pedestal. The mounting mechanism includes a circular metal(?) plate which is attached to the shell using six equally spaced flathead screws/bolts[26]. A metal (?) rod is secured to the centre of this plate and the centre of the pedestal. It is this mechanism which allows the chair to rotate. The visible surfaces of the pedestal and mounting plate are painted red. Prior to the painting of the mounting plate two pieces of 10 mm wide transparent self-adhesive tape were adhered to the plate. Their purpose is not evident. The rod and the bottom surface of the pedestal have no apparent paint or other finish applied. The dimensions of the pedestal are detailed in Figure 25.

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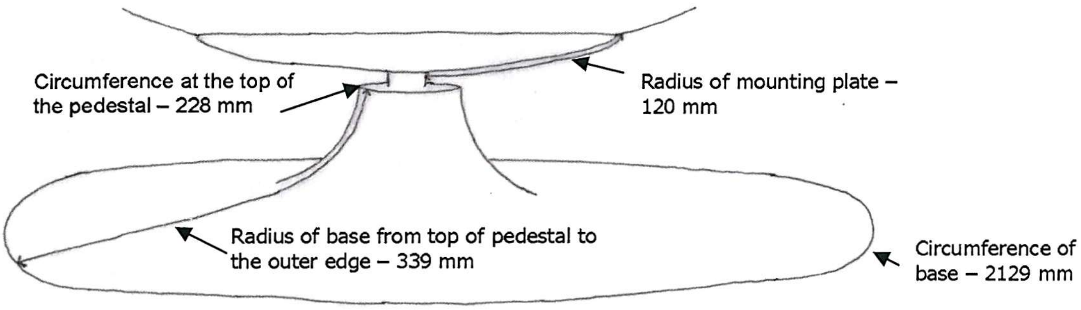
[26] It was reported by Michael Marks, 20th Century Marks that there is a matching metal plate on the inside of the shell. No evidence of such a plate was found. However, as access to this area of the chair was limited due to still secure upholstery pads the possible existence of such a plate remains an open matter.

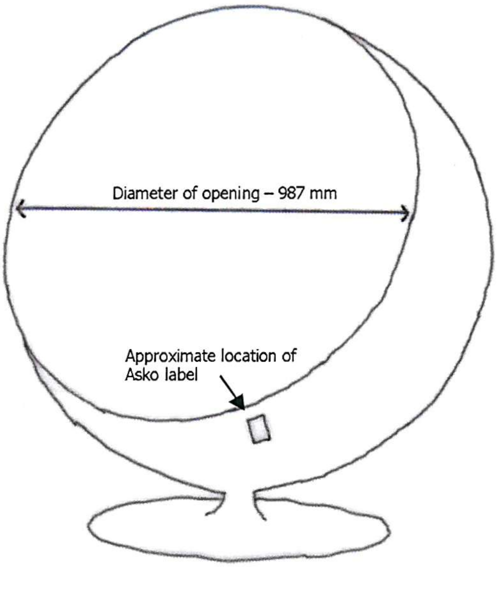


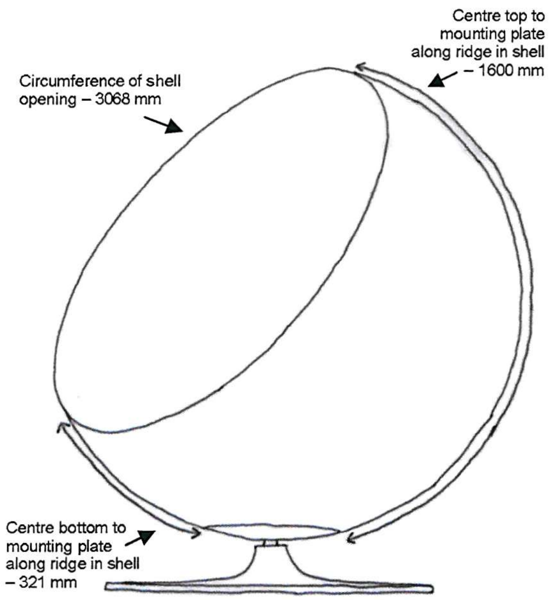
▲ **Figure 25: The basic structure and dimensions of the pedestal base of the *Globe*.**

1.3.3 – Frame dimensions (Figures 26 & 27)

At its widest points the frame measures:

- 1200 mm high
- 977 mm wide
- 660 mm deep



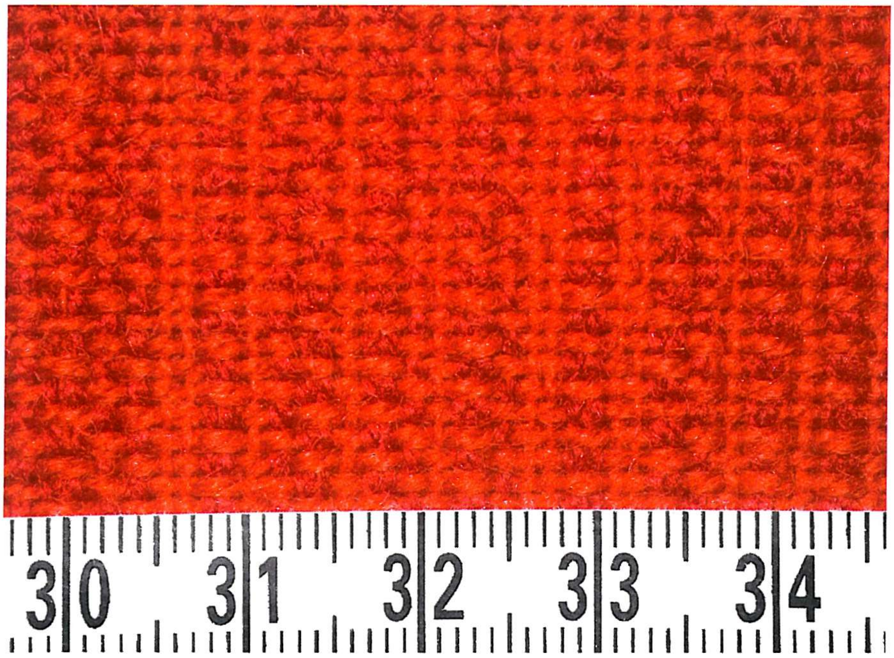


▲ **Figure 26: Additional dimensions of the *Globe* - note location of the previously described label (Section 1.3.1).**

▲**Figure 27: Additional dimensions of the *Globe*.**

1.3.3 – Upholstery

The interior of the shell is upholstered with five foam triangles which have been covered in orange and red woven fabric. This same fabric is used to cover the piping attached to the shell and cover the two loose box cushions. In the original invoices for the chair the fabric is identified as Siam Bazar #5251 but no origin of the fabric is given (Figure 28). Bert Ufermann, managing director of ADELTA and Michael Marks, owner of 20th Century Marks (2CM), a twentieth century furniture retail establishment in Essex, England, indicated that the fabric used in the early *Ball* chairs is the same as that used today.[27] The fabric currently being used is Hallingdal by Kvadrat and it is 70% wool and 30% viscose. However, Alice Rasmussen, at Kvadrat confirmed that the fabric on the V & A's chair is not Hallingdal and is not anything that was ever supplied by Kvadrat. She suggested it might have been produced by Maijata Metsovara or Mary Block but this suggestion was not able to be confirmed or contradicted.[28]



◄ Figure 28: An image of 49 mm of weave detail with the wefts oriented in the horizontal direction. V & A – Circ. 12-1969 (Photo – J. Wickens)

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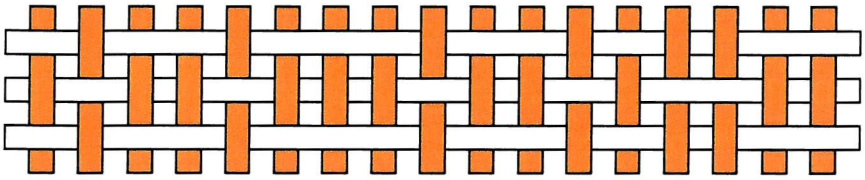
[27] Personal conversations on 29 April 2004 and 20 August 2004 respectively.

[28] Personal e-mail communication from Alice Rasmussen on 4 May 2005

The fabric is 100% wool[29] and woven in a structure based on an extended plain weave of 6 warps and 7 wefts to 10 mm (Seiler-Baldinger 1994). The wefts are always orange double s-plied yarns and the warps are single or double s-plied orange or red yarns. Each warp is made up of one, two or three of these single or double s-plied yarns. The pattern repeats every 190 mm with approximately 20 mm of the pattern but not the colour variations reproduced in Figure 29.



◄ Figure 29: Approximately 20 mm of the 190 mm pattern repeat in the top cover fabric showing the use of one, two or three yarns per warp to produce a variation on a plain weave. Warps in orange and wefts in white.

The foam triangles are made of polyether polyurethane foam.[30] They are approximately 45 mm thick with additional *in situ* measurements supplied in Figures 30 & 31.

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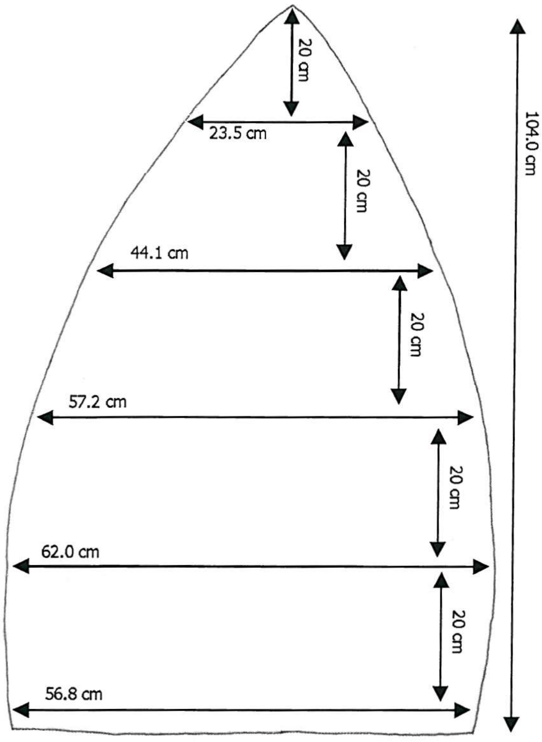
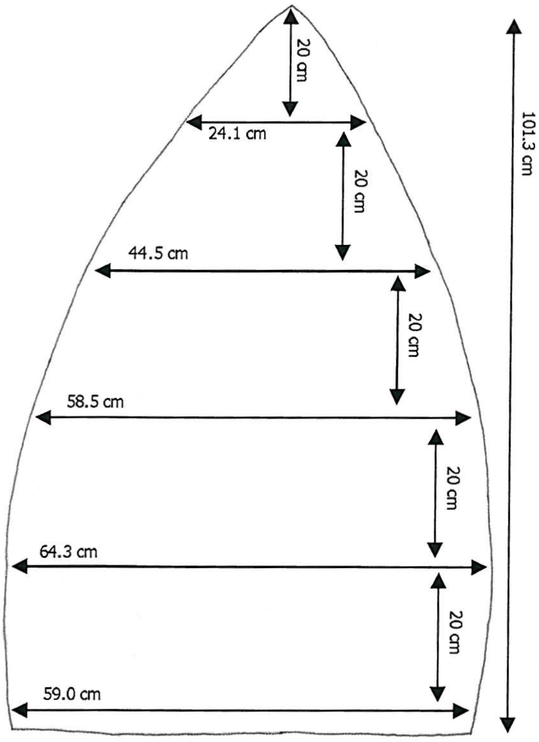
[29] Unless otherwise noted, all fibres referred to in this thesis have been identified by examining longitudinal sections and cross-sections of the fibres with polarizing light microscopes and comparing the results to photographs of known samples in The Textile Institute (1970) or slides of known samples in the Textile Conservation Centre slide collection.

[30] This identification was carried out using Fourier Transform Infrared Spectroscopy (FTIR). It and all other such analysis referred to in this document were carried out by acquiring infrared spectra with a Perkin Elmer Spectrum One FT-IR Spectrometer equipped with a universal attenuated total reflectance (ATR) sampling accessory. Each sample was placed on the diamond crystal of the ATR accessory and clamped in place. Spectra were recorded from 4000 to 400 cm^{-1} with a resolution of 8 cm^{-1}, and averaged over 16 or 64 scans and processed with Thermo Galactic Grams/AI (7.02) software. Identification was carried out by comparing the spectra of samples of unknown material to spectra of known samples also collected on the same machine. Experimental spectra and corresponding reference spectra used for identification are supplied in Appendix 2 if not located in the main text of this document.



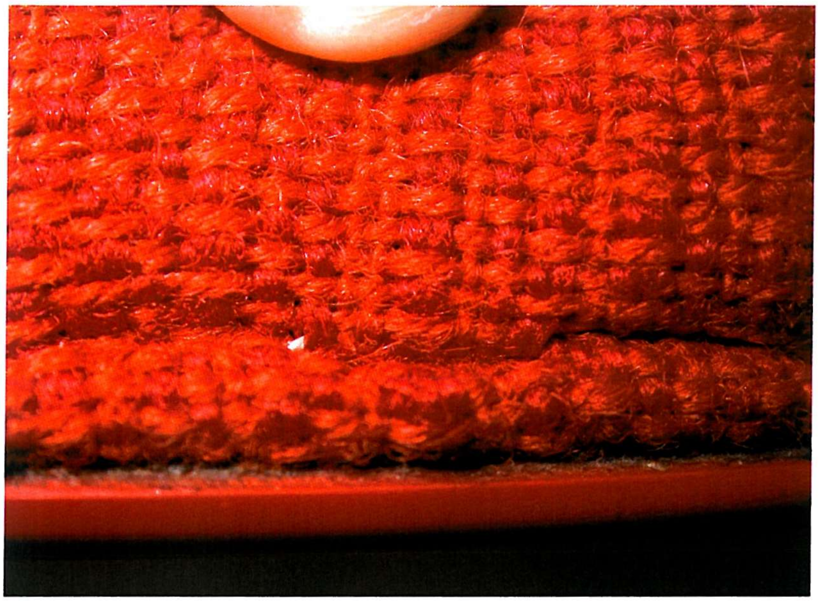
▲ **Figure 30:** ***In situ*** **measurements of the bottom proper left pad of the** ***Globe***



▲ **Figure 31:** ***In situ*** **measurements of the pad at the top centre of the** ***Globe***

With these two primary materials the sphere of the *Globe* is upholstered. A row of piping is adhered, with an inconclusively identified adhesive, along the outside edge of the internal surface of the shell. This piping is constructed of a cord of unidentified material covered in the described top cover fabric. The fabric is oriented so the wefts run parallel to the edge of the shell and the fabric extends into the shell by approximately 40 mm in the warp direction. The fabric is unfinished along the edge located 40 mm into the shell and seamed at the bottom centre.

In order to accommodate the stabilizing bars, channels have been cut into the reverse of the foam pads and a wedge has been cut from the reverse of each tip at the point where all five tips meet at the back of the chair. Black felt tip pen(?) lines on the edge of the reverse of one of the pads suggests the channels may be marked on the pad before cutting. Fabric is adhered to the entire obverse and approximately 40 mm of the reverse of each pad along each of the two longer edges using a polychloroprene based adhesive.[31, 32] The fabric is oriented with the warps radiating from the back centre point of the chair out to the edges and was probably tensioned a bit during the application process.[33,34] The pads where adhered to the interior of the shell using an adhesive for which no sample could be obtained. Once in place the fabric at the front edge of each pad was stitched to the piping using a white, cotton(?) thread. The 45 mm vertical edges of each pad were stitched together and the five tips at the back centre of the chair were secured to each other with a few stitches (Figures 32 - 34).



▲ Figure 32: A detail of the stitching used to secure the top cover to the piping. V & A – Circ. 12-1969 (Photo – J. Wickens)

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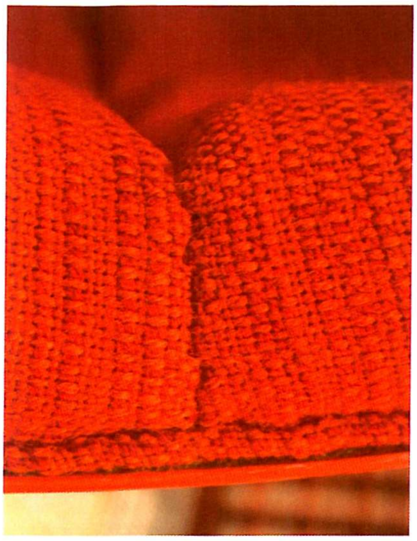
[31] Identified by FTIR

[32] The current upholstery techniques used on *Ball* chairs and the historical use of polychloroprene adhesives (Allen 1984) suggest this adhesive would have been sprayed onto both the foam and fabric, the materials would have been left until the volatile solvent component of the adhesive had evaporated and then the two adhesive surfaces would have been brought together to create a bond between the two. An adhesive designed to be used in this fashion is commonly called a contact adhesive (Section 2.3.1).

[33] Section 1.5.3 will document that the fabric has separated from much of the foam pads. Examination reveals that the fabric would probably have to be slightly stretched in order to re-adhere it to the entire obverse surface of these pads suggesting this was probably done during its initial application. An examination of the one area of top cover fabric on VDM - SSK-1002 (Section 1.6) that has separated from the foam is consistent with the conclusion.

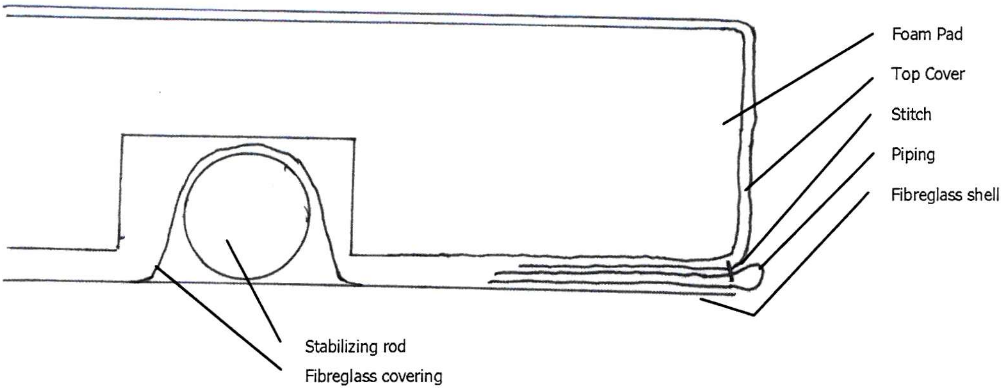
[34] In 2004, the upholstery pads are prepared to this point in the upholsterer's workshop and then taken to the factory for fitting into the chairs (Personal conversation with Bert Ufermann, 6 May 2004). Whether this was the process in 1968 is not known.



▲ **Figure 33: A detail of the seam stitched between the front vertical edges of each cushion. V & A – Circ. 12-1969 (Photo – J. Wickens)**

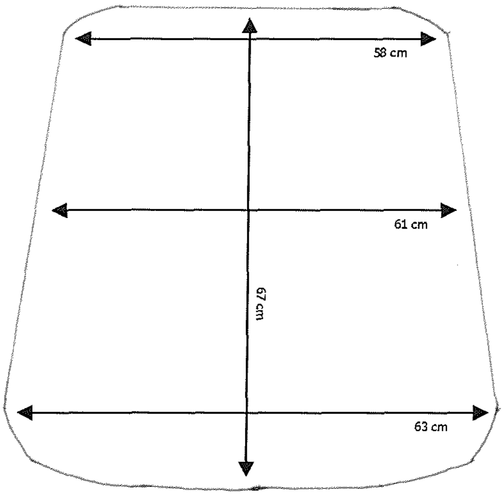
▲ **Figure 34: A detail of the stitching securing the five tips of the pads at the back of the shell. V & A – Circ. 12-1969 (Photo – J. Wickens)**

A cross-sectional drawing of the outer approximately 80 mm of the shell and upholstery is provided in Figure 35. It is believed to be accurate for all points around the circumference of the opening of the shell other than those within approximately 50 mm of each edge of the foam pads. In these locations the use of adhesives, fabric and stitching changes slightly.

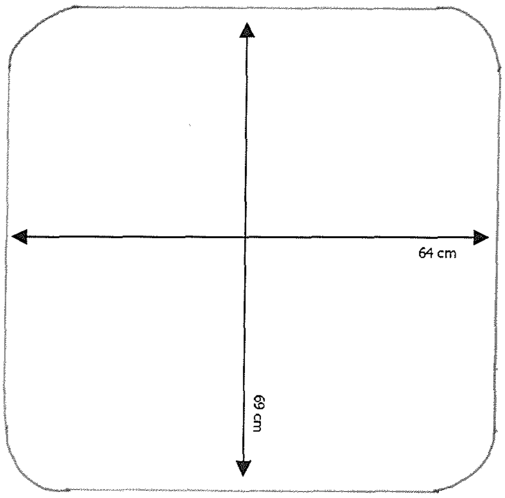


▲ **Figure 35: A cross-section of the apparent construction of the upholstered shell at the outer edge.**

The upholstery is finished with back and seat cushions of slightly different dimensions (Figures 36 & 37). The method of construction used for each cushion appears to be identical. The top cover of each cushion is pieced, with the fabric previously described, in five parts: front/top panel and a back/bottom panel of identical shape, a side panel which covers three sides and a two part zipper panel at the bottom or back. The fabric is oriented with the warps running across the shorter dimensions of the side and zipper panels and the longer dimensions of the other two. The panels are stitched together with red synthetic(?) thread. Two different methods of seam construction are used to attach the panels to each other and a third is used to fasten a silver coloured metal(?) zip mounted on a charcoal gray fabric to the bottom/back portion of the side panels.



▲ **Figure 36: The dimensions of the front face of the loose back cushion. The cushion depth is 10 centimetres (cm).**



▲ **Figure 37: The dimensions of the top face of the loose seat cushion. The cushion depth is 10 cm.**

When the zips are opened they reveal, in each cushion, a machine stitched, cream coloured, plain weave, cotton(?) cushion cover. A 90 mm length of one seam in this cover, just inside the zip of the back cushion was released[35] and in so doing revealed that each cushion appears to be constructed in five layers. The inner most layer is a block of polyether polyurethane foam.[36] This block is wrapped in a layer of approximately 10 mm thick wadding.[37] The wadding is wrapped with a very loosely woven fabric from which no sample could be removed. These three layers of padding are encased in the cotton cushion cover just described and then covered with the decorative cover previously described (Figure 38).

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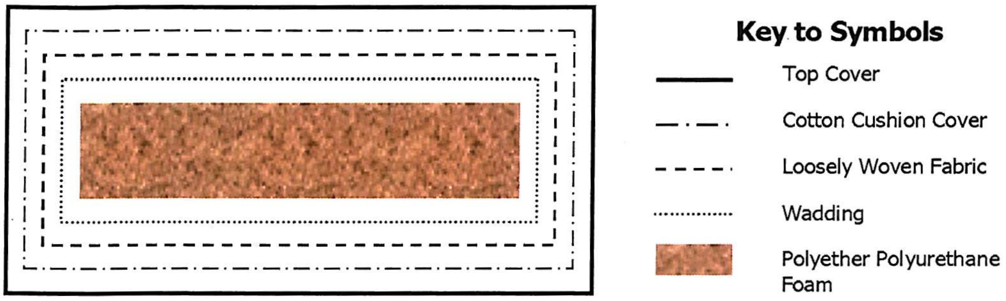
[35] Upon completion of the examination the seam was re-stitched through every third original stitch hole using Gutermann 100% polyester white thread.

[36] Identified by FTIR

[37] Materials identification was inconclusive



▲ Figure 38: A cross-section of the layered structure found in the loose back cushion which is likely to have been used in the loose seat cushion as well.

1.4 – Construction of other *Ball* chairs

The examination of other *Ball* chairs and related items has clarified and revealed further construction details relevant to the *Globe*. Of most use in this respect was the acquisition and subsequent detailed examination of a full set of *Ball* chair shell upholstery pads. These pads were removed by Michael Marks from a *Ball* of an unknown date. The removal had taken place when he was having the chair re-upholstered for a client. The five foam pads, with two top cover layers still attached, had then been retained by Mr. Marks, in his store rooms for a number of years. He used them for reference material when making new pads for *Ball* chairs in the process of being restored. He donated the pads to the project described here to be used in any fashion identified as necessary and appropriate (Figures 39 & 40).

▲ Figure 39: The obverse of one of the pads donated by Michael Marks showing parts of the adhesive coated foam surface, the reverse of the original blue top cover and the obverse of a second green top cover. (Photo – J. Wickens)

▲ Figure 40: The reverse of one of the pads donated by Michael Marks showing the reverse of the original blue top cover at the edges and the channels cut to accommodate the stabilizing bars. (Photo – J. Wickens)

Initial examination showed the pads to be of an apparently similar size and shape to those in the *Globe* with four of the five pads retaining two partially attached top covers. The outer most was a green, boucle fabric. The inner most a blue and purple plain weave which again appeared to be at least very similar to that on the *Globe*. Further investigation revealed that the inner most top covers were identical in all but colour to those on the *Globe*. As explained in Section 1.3.3, this fabric is not the fabric which has been used by ADELTA since the reintroduction of the chairs in 1992. Its presence on the pads therefore places a likely date for their production and covering in the 1966 to c. 1980 time period. FTIR analysis showed the pads to be composed of polyether polyurethane foam with a polychloroprene based adhesive covering the obverse surface of each pad as well as approximately 40 mm along the two longer edges of the reverse of each pad. The spectra of both materials are very similar to those obtained from the corresponding materials found in the V & A's chair (Figures 41 - 44). This fact suggests that the pads are very similar in composition and condition to those on the *Globe*.[38] With fabric, foam and adhesive composition and foam and adhesive condition linking the 2CM pads to the *Globe* pads further examination of the pads to gather details of construction and condition which could be applied to the *Globe* became a reasonable undertaking.

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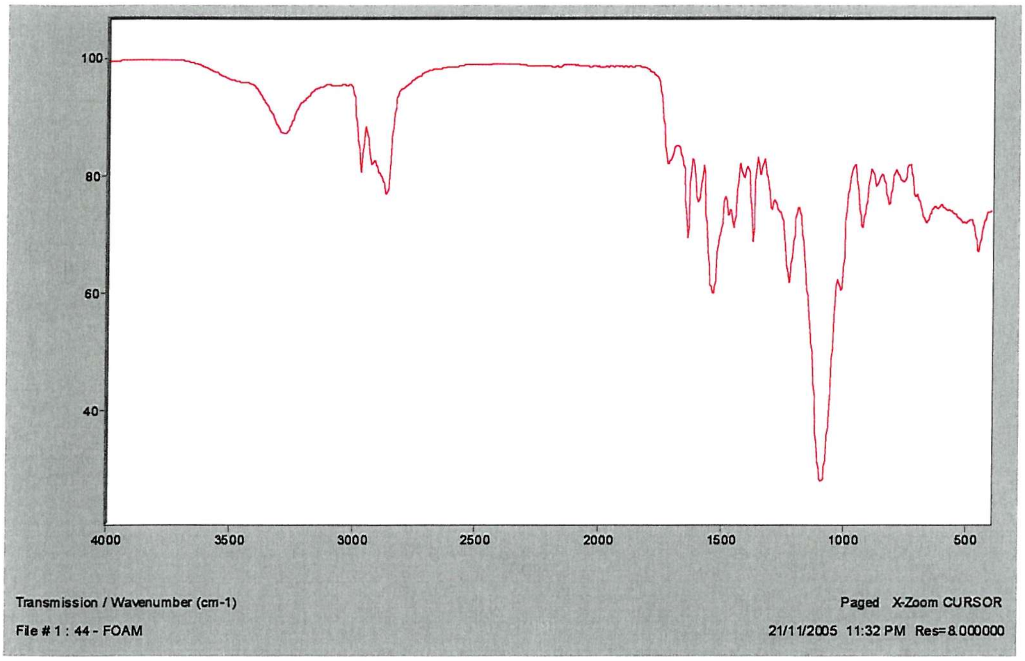
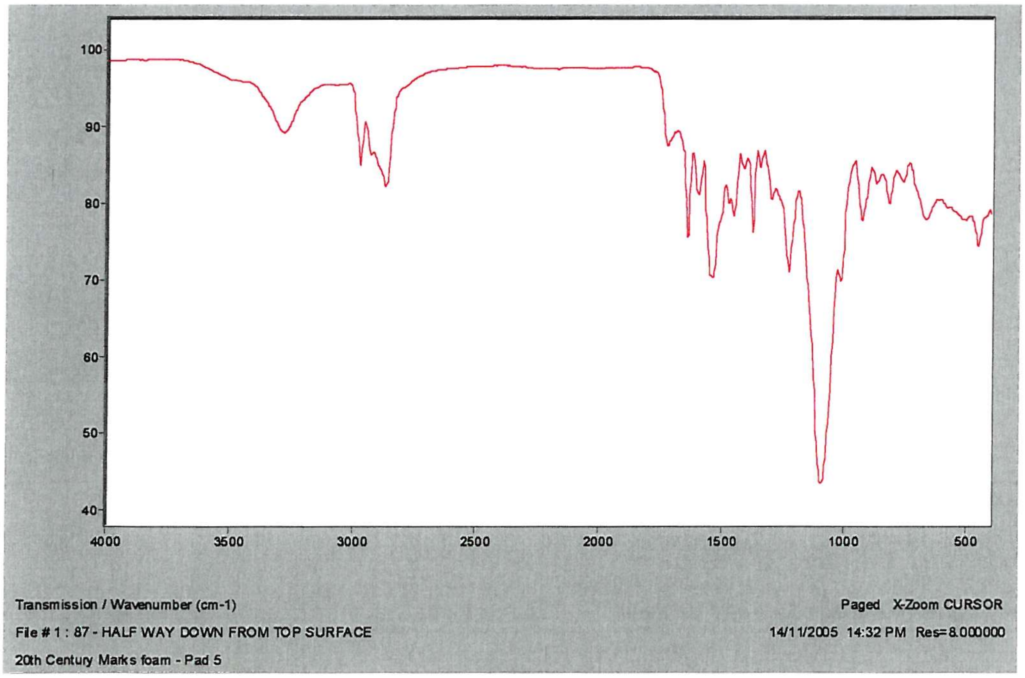
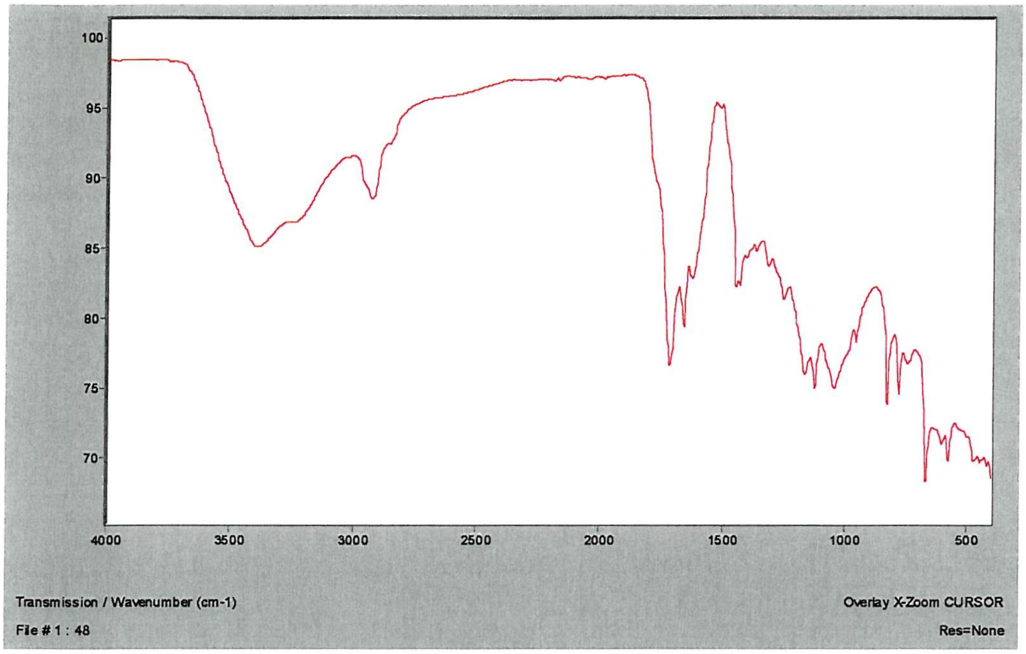
[38] Personal conversations with Scott Williams, Senior Conservation Scientist, Canadian Conservation Institute, 10 June 2004 and Dr. Paul Wyeth, Visiting Senior Research Fellow, Textile Conservation Centre, 9 January 2006



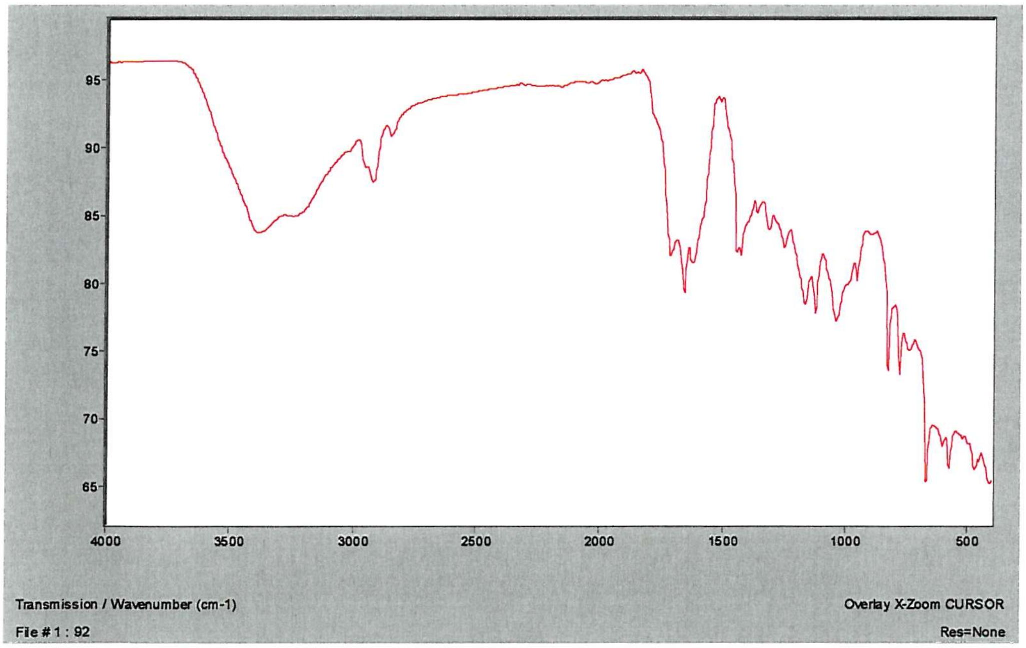
▲ **Figure 41: FTIR spectrum of the polyether polyurethane foam used in the shell upholstery pads of the *Globe*. The sample was removed from the edge of the proper left side pad.**



▲ **Figure 42: FTIR spectrum of the polyether polyurethane foam used in the shell upholstery pads donated by 2CM. The sample was removed from the interior of Pad 5.**

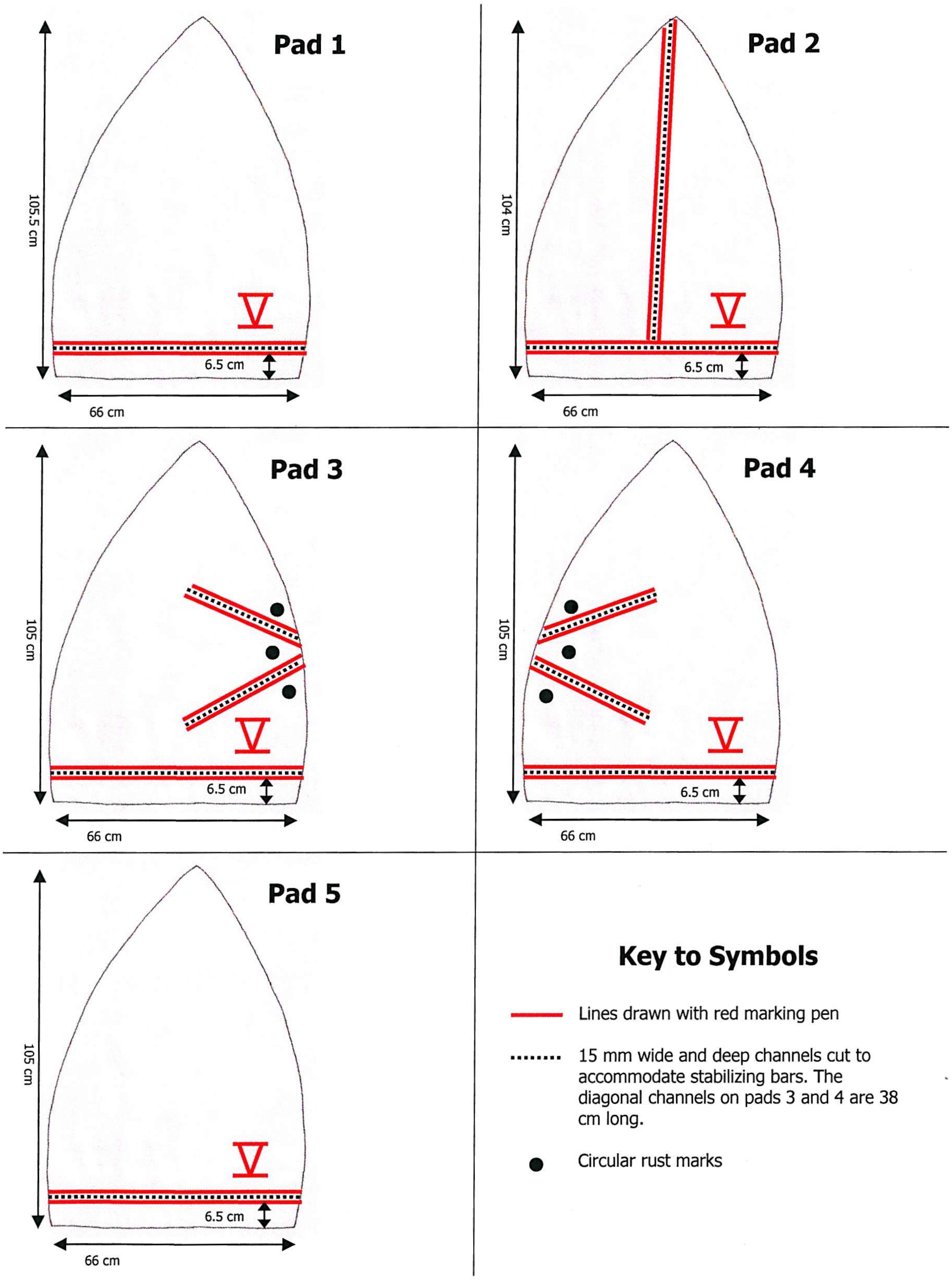


▲ **Figure 43: FTIR spectrum of the degraded polychloroprene based adhesive on the obverse surface of the shell upholstery pads of the *Globe*. The sample was removed from the obverse of the proper left side pad.**



▲ **Figure 44: FTIR spectrum of the degraded polychloroprene based adhesive on the obverse surface of the shell upholstery pads donated by 2CM. The sample was removed from Pad 5.**

The reverse of each pad was sketched and each was assigned a number (Figure 45). All references to the pads from this point forward will be made using 2CM Pad followed by the appropriate number.

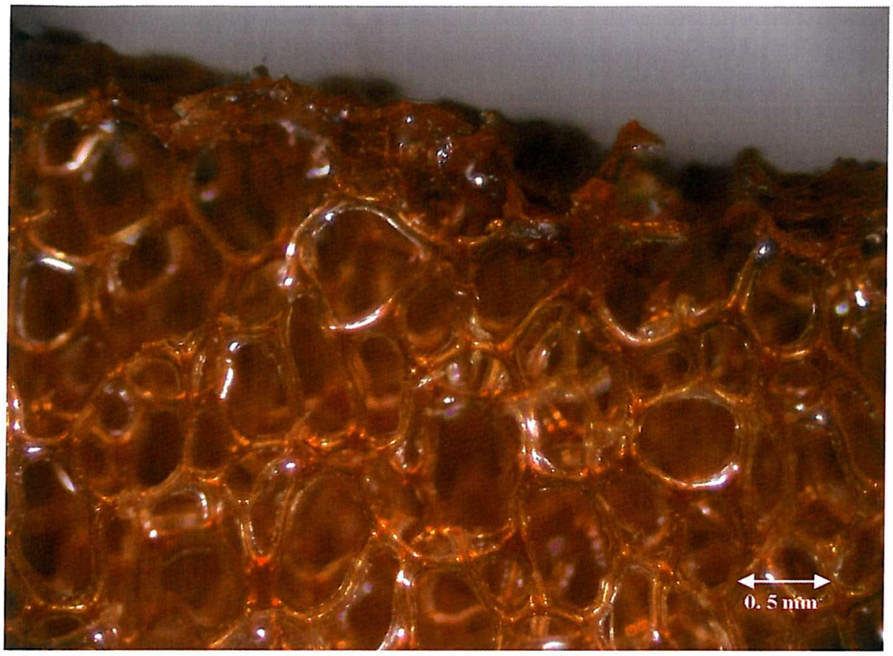


▲ Figure 45: Sketches of the reverse of five foam shell upholstery pads removed from a *Ball* chair by Michael Marks of 20th Century Marks.

From these sketches and the examinations carried out while producing them, it is possible to confirm two construction details suggested above. The channels cut to accommodate the stabilizing bars were marked before they were cut. In the *Globe* the evidence of this is black felt tip pen(?) lines visible at the edge of the reverse of one pad. In the 2CM pads the evidence is red felt tip pen(?) lines along both edges of all channels which have been cut. Also, no adhesive was used to secure the top cover fabric to the foam along any of the vertical edges of the pads or along the front edge of the reverse as evidenced by the lack of adhesive on all 2CM pads in these locations.

It is also possible to determine several construction details which were not clear following either examination of the *Globe*. If the pads in the *Globe* were removed and placed flat on a surface they would measure approximately 660 mm wide and 1050 mm long. Based on the length of the channels cut in the pads, the criss-crossing stabilizing bars at the base of the shell are approximately 760 mm long. Based on circular rust marks found between the criss-crossing channels in 2CM Pad 3 and 2CM Pad 4, there are six exposed screws/bolts in similar locations to those holding the mounting plate to the external surface of the shell. These screws/bolts are likely to be either the other end of those seen on the outside of the chair or the fasteners for the metal plate it has been suggested is mounted on the inside of the shell (Section 1.3.2, Footnote 26). The adhesive layer along the edges of the reverse of the pad is thicker and less consistent than that on the obverse which may indicate the adhesive was applied to the two areas using different methods. Finally, when the top cover fabric was wrapped around the sides and reverse of each pad during the upholstery process it was cut along the sides of every channel it covered.

Stereoscopic examination of different areas of the 2CM pads revealed the following information. Due to the lack of a skin on any surface of any of the five 2CM pads it is likely the foam triangles are cut from slabstock foam rather than moulded. Cell shape indicates that the primary direction of foaming during manufacture was in the direction now oriented along the pad depth (Klempner & Sendijarevic 2004). Cell diameter is highly variable, from less than 0.5 mm to occasionally more than 1.0 mm. The adhesive applied to the obverse surface of the pads penetrated the foam by as much as 0.5 mm. (Figure 46 provides a visual picture of these last three details.)



◄ Figure 46: A cross-section of 2CM Pad 5 with the obverse surface at the top of the image. The cells in the image are primarily elongated in the vertical direction indicating that this was the direction of foaming during manufacture. The darker brown substance at the top of the image is the degraded adhesive. (Photo – J. Wickens)

Two samples were cut from 2CM Pad 3. Sample 1 – 37 mm x 21 mm x 34 mm with a mass of 0.646 grams (g). Sample 2 – 39 mm x 24 mm x 23 mm with a mass of 0.595 g. From these measurements the density of the foam was calculated to be approximately 26 kilograms per cubic metre (kg)/(m)^3.

These details relating to the physical structure of the foam can only be 100% conclusively linked to the 2CM pads from which they were gathered. However, accepting the likely similar date of manufacture and method of application of these pads to those on the *Globe*, they are likely to be representative of the *Globe* pads as well.

An examination of one of the three *Ball* chairs in the collection at the VDM, SSK-1002 (Figure 47),[39] expanded knowledge about four specific construction details of the *Globe*. First, the upholstery of this chair is clearly in better condition than that of the *Globe*. The shell edges are however is worse condition with a few good sized chips revealing an additional visual picture of the gel coat(?) and fibreglass(?) layers (Figure 48). Second, as with the V & A's chair, a section of one seam of the internal, plain weave, cotton(?) cushion cover was released to reveal details of the internal structure of the cushion. In this case, when the seam was released layers could be pulled back all the

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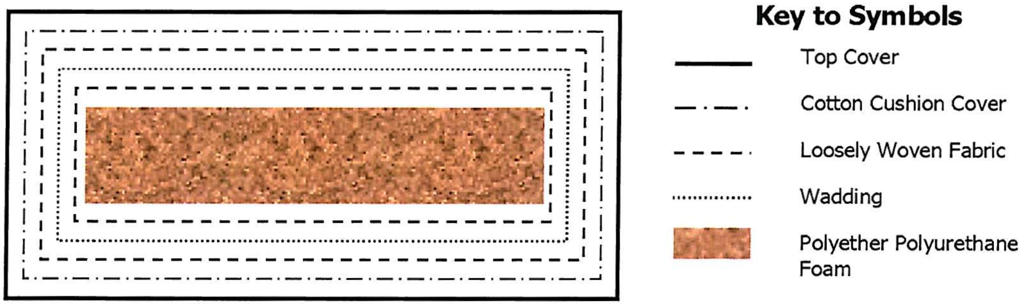
[39] Carried out at the VDM on 4-6 April 2005 at the kind invitation of Kathrin Kessler, Conservator, AXA Art Conservation Project in cooperation with the Vitra Design Museum

way to the polyether polyurethane foam pad at the centre of the cushion (Figure 49). This increased level of access as compared to that gained when the seam of the *Globe* chair back cushion was opened made it possible to determine that the foam pad at the centre of the cushion is 30 mm to 40 mm thick and the wadding wrapped around the pad is 10 mm to 20 mm thick. It also revealed that the loosely woven fabric detailed as the middle layer in the five layer construction of the *Globe* back cushion (Figure 38, Page 32) probably actually serves as the second and fourth layers in a six layer object (Figure 50).

▲ Figure 47: A *Ball* chair with upholstery in much better condition than that on the *Globe*. VDM - SSK-1002 (Photo – J. Wickens)

▲ Figure 48: A detail of the *Ball* chair in Figure 47 showing a cross-section of the gel coat(?) and fibreglass(?) shell. VDM - SSK-1002 (Photo – J. Wickens)

◄ **Figure 49: A detail of the back cushion of a *Ball* chair showing some of the layers used in its construction. VDM - SSK-1002 (Photo – J. Wickens)**



▲ **Figure 50: A cross-section of the layered structure found in the loose back cushion of VDM - SSK-1002 which suggested that the structure in the loose cushions of the *Globe* is probably six layered rather than five.**

Additional details gathered during the investigations described above as well as:

- the examination and analysis of upholstery samples provided by the current upholsterer of *Ball* chairs
- the examination of a *Ball* in the collection at the MMFA, D87.245.1[40]
- the examination of a second *Ball* in the collection at the VDM, MSK-1001-1
- the review of a report about a *Ball* sold at auction at Sotheby's London in 2005[41]
- the examination of photos of a third *Ball* in the collection at the VDM, MSK-1001-2, and numerous other *Ball*s found in recent magazines, newspapers and world wide web pages
- discussions with Michael Marks and Bert Ufermann

have revealed many additional details about the construction of *Ball* chairs. These details highlight some of the similarities and differences in the chairs that have come to be in the 41 years since the manufacture of *Balls* began.

They all appear to be constructed in the same general way. A gel coat(?) and fibreglass(?) shell is mounted on a metal(?) pedestal. The shell is upholstered with five foam(?) wedges to which top cover fabric has been adhered and a loose back cushion and seat cushion sit within this upholstered shell.

Polyether polyurethane foam was used for the shell upholstery pads and the inner layer of the loose cushions early on in the production of the chairs, as evidenced by the analysis of the *Globe*. This same basic material is used for parallel purposes today as evidenced by the analysis of upholstery padding samples provided by the current upholsterer of the chairs.[42] Analysis of foam samples removed from two of the *Ball* chairs in the collection at the VDM also proved to be polyether polyurethane foam. This consistency across analysis suggests that this material has been used through out the production of the chairs. There is no doubt however that the specific formulation of the polyurethane material has changed in the almost 40 years between the production of these two sets of samples (Brydson 1999; Buist 1978; Buist & Gudgeon 1968; Klempner & Sendijarevic 2004). One specific change which can be identified is the

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[40] Carried out at the Montreal Museum of Fine Arts on 25 May 2005 at the kind invitation of Diane Charbonneau, Curator of Non-Canadian Decorative Arts after 1960

[41] Lot 146, Sale L05814, Fine Decorative Arts & Design from 1870, New Bond Street, London

[42] Identified by FTIR

inclusion of a fire-retardant which would not have been included when the *Globe* was produced.[43]

The fabrics used to upholster the *Globe*, one of the chairs at the VDM, SSK-1002 (Figure 47, Page 40), the Sotheby's chair (Figure 70, Page 56) and the 2CM pads all appear to be very similar and therefore, as discussed earlier (Section 1.3.3), were not supplied by Kvadrat. This may date all of the chairs to an early stage in their production. The fabric used to upholster the chair at the MMFA is different, at least in weave pattern, from those above. As this chair dates from the Asko period of manufacture of the chairs, if the fabric is original it would show that more than one fabric type was used to upholster the chairs in this time period. The fabric used in the VDM, MSK-1001-1, is red leather. The date of its production is unclear although as the pedestal is mounted externally, based on the detail below, it may date from the Asko period or perhaps the early years of ADELTA production. It is possible that these last two fabrics are the product of re-upholstery projects and therefore any further conclusions need to be avoided. No other specific fabric details were available from the examinations described above.

Ufermann highlighted two intentional changes in production which have come about since the reintroduction of the chair by ADELTA. The gel coat is now formulated to be more resistant to 'sun and weather exposure' in order to make the chairs more durable when subjected to outdoor use. Secondly, the pedestal is now fixed to the shell internally rather than externally, a design alteration made by Aarnio, himself.[44] None of the examined chairs have been constructed with this new mechanism but a chair with one could clearly be dated to the ADELTA period of production.

Although largely similar, several slight variations in pedestal construction have been noted. The VDM, MSK-1001-2, has a collar at the top of the pedestal base (Figure 51).[45] The VDM, SSK-1002, has a clear label with a black Asko symbol and text adhered to the pedestal mounting plate and no emblem moulded into the gel coat. The VDM, MSK-1001-1, has a base that is only 2.5 mm thick while all other examined

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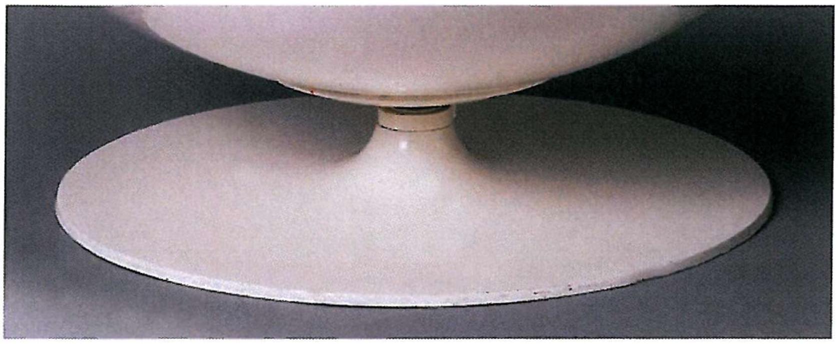
[43] Personal conversation with Bert Ufermann, 29 April 2004

[44] Personal conversation with Bert Ufermann, 29 April 2004

[45] Michael Marks commented that he thinks this is an early, unsuccessful variation.

bases are 10 mm thick. It also has a bumper which keeps the chair from making a full revolution[46] and the mounting plate is secured to the shell with screws/bolts with a hexagonal socket rather than a flathead screwdriver slot.



◄ Figure 51: A detail of a *Ball* chair pedestal revealing the collar at the top of the base. VDM – MSK-1001-2 (Photo – VDM)

The construction variations noted during these investigations were most numerous in the VDM, MSK-1001-1, chair (Figure 52). Other than those already mentioned they are primarily the result of the use of leather rather than fabric to upholster the chair and the installation of speakers. These details have been recorded but they will not be included here.[47]

◄ Figure 52: A *Ball* upholstered in red leather with speakers installed. VDM – MSK-1001-1 (Photo – J. Wickens)

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[46] This chair is fitted with speakers and the wires which would be used to attach them to a sound source exit the chair just above the rear edge of the pedestal mounting plate. Presumably the bumper has been fixed in place to keep the wires from wrapping around the chair as it revolves.

[47] Notes held by the author

1.5 – Condition of the *Globe* – December 2004

The majority of the *Globe* appears to be in a generally stable condition showing few signs of degradation or damage. The obvious exception to this is the fact that over the majority of the shell the top cover fabric is no longer adhered to the foam upholstery pads. This has left the unsupported fabric and the underlying foam in a vulnerable position and raised concerns regarding the stability of the foam (Figure 53).

◄ Figure 53: The *Globe* on display in the Twentieth Century Study Galleries, 12 May 2004. Visual signs of degradation in the sagging top cover are clearly apparent. V & A - Circ. 12-1969 (Photo – J. Wickens)

1.5.1 – The shell

The outside of the shell is generally smooth and shiny with no signs of cracking, separation from the underlying fibreglass(?) layer or discolouration. It has numerous black, grey and cream scuff marks, primarily on the lower half and the lower third of the edge is marked and chipped. The largest chip, 9 mm x 7 mm, is located 750 mm up from the centre bottom on the proper left edge (Figure 54). It reveals a more transparent layer of gel coat(?) but it does not penetrate through to the fibreglass(?) layer. All of these marks are consistent with what one might expect if the chair were to be bumped on a wall or door frame or be bumped into with a hard object. No testing was carried out but it appears the majority of the marks might be easily cleaned away.

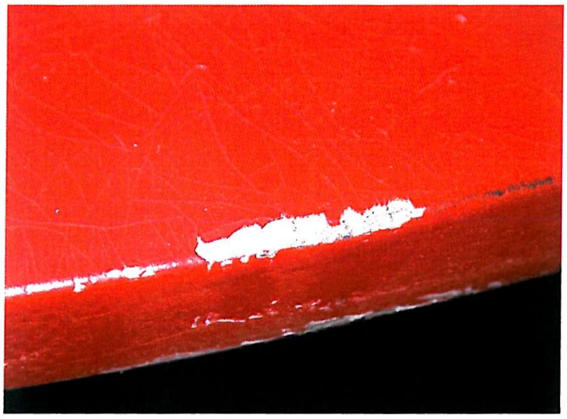
◄ Figure 54: An image of the largest chip in the edge of the shell which is located 750 mm up the proper left side from the bottom centre. V & A - Circ. 12-1969 (Photo – J. Wickens)

There are two other marks worthy of specific note. First, there is a small black hole which appears to be a manufacturing defect 387 mm back from the upper edge of the chair and 550 mm away from the ridge in the gel coat(?) on the proper right side. The second is 110 mm back from the top edge and 60 mm from the ridge. It appears to be a heavy, black, felt tip pen(?) mark.

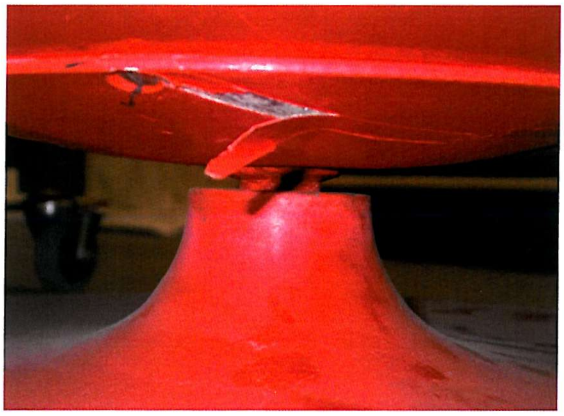
The internal surface of the shell is concealed by the upholstery making it impossible to properly assess its condition. Small portions of it can be accessed by carefully pulling the triangular upholstery pads away from each other. These small glimpses reveal no signs of degradation or damage.

1.5.2 – The pedestal

The pedestal, rod and mounting plate appear to be in a stable condition with no signs of rust or other corrosion products present. The paint layers on both the pedestal and mounting plate show a few more signs of damage. There are fine, irregular, intersecting cracks which criss-cross the entire painted surface. Larger scrapes and chips revealing both bare metal(?) and a yellowish/white layer of paint(?) are found on the outer edge of the pedestal (Figure 55). One of the two pieces of transparent self-adhesive tape has come away from the mounting plate taking a 10 mm x 60 mm section of paint with it. Bare, black metal(?) is revealed beneath the tape. A layer of dust covers most of the pedestal (Figure 56). The swivelling mechanism is still functional.



▲ Figure 55: Paint chips at the edge of the pedestal with barely visible fine cracking across most of the visible surface. V & A - Circ. 12-1969 (Photo – J. Wickens)



▲ Figure 56: Evidence of peeling transparent self-adhesive tape with a heavy dust layer visible in the lower half of the image. V & A - Circ. 12-1969 (Photo – J. Wickens)

1.5.3 – Upholstery

The top cover fabric appears to be in a generally stable condition. It does not feel brittle. There is no evidence that it is shedding fibres. There are no signs of abrasion. There are no signs of fading. A layer of dust has accumulated on the surfaces covering the lower two upholstery pads to the right and left of the loose seat cushion.[48] The fabric is still secured to the underlying foam layer beneath the back cushion and the rear two-thirds of the seat cushion although gentle manual examination of these areas leaves the impression it would take only minimal force to separate the layers. This generally stable textile is however vulnerable due to the fact that it is no longer supported by the

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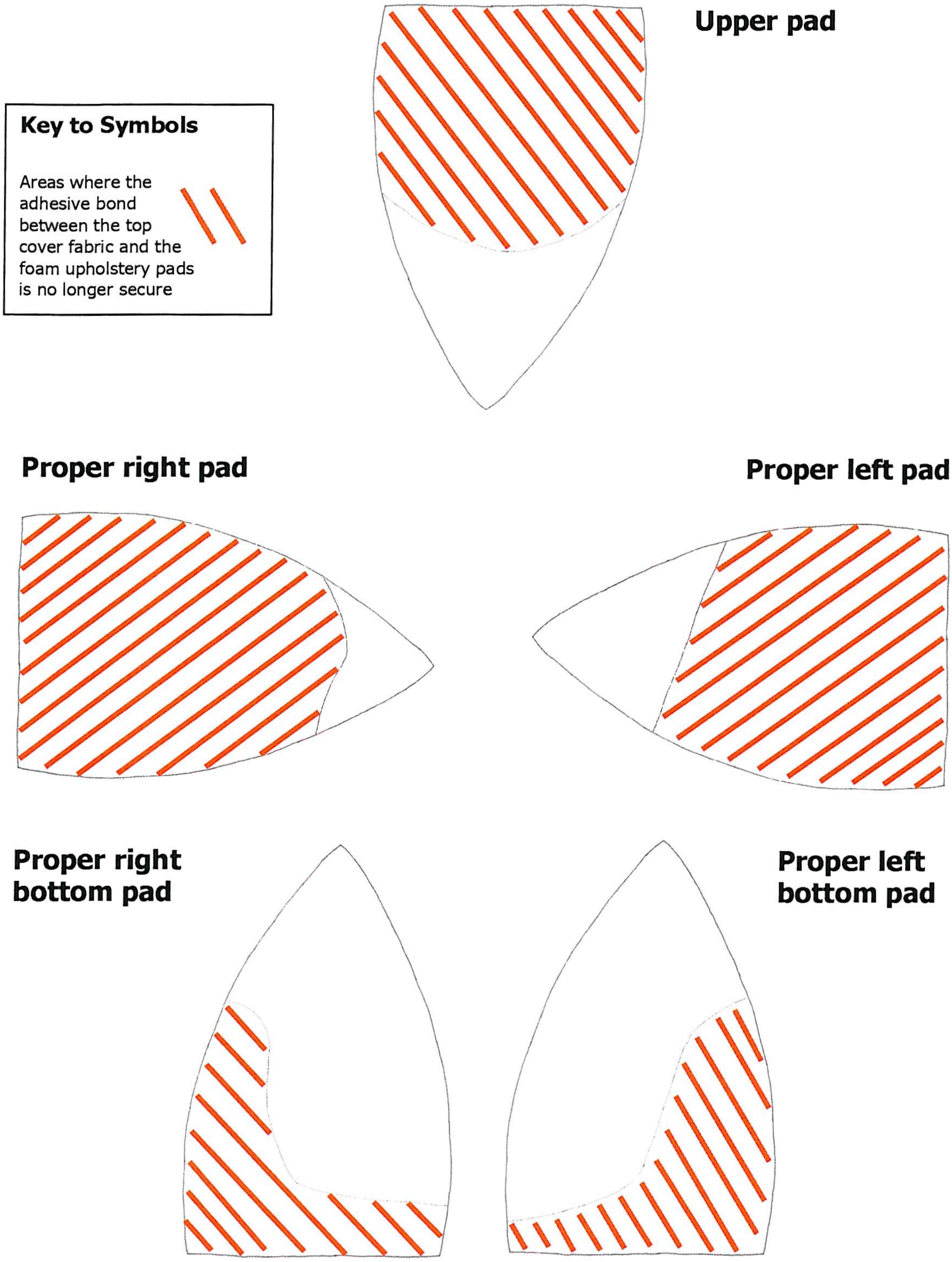
[48] Following the December 2004 examination of this chair, it was surface cleaned using low-powered vacuum suction and the dust on the upholstery and pedestal were easily cleaned away.

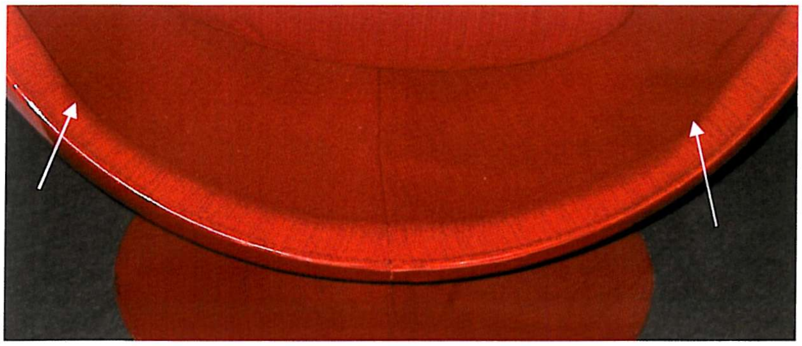
underlying foam layer over the rest of the obverse surface of this upholstery padding (Figure 57).



▲ Figure 57: Sketches of the five foam pads used to upholster the shell of the *Globe* showing where the bond between the top cover fabric and the foam is still secure and where it is not.

The foam used in the shell padding is in much better condition than one might expect of almost 40 year old foam (Griffith 1997; Lovett 2003; van Oosten & Keune 1999). It is not brittle, crumbling or sticky. No evidence of disintegrating foam was found collecting in the billows of the no longer adhered fabric or falling through the weave structure. The foam retains some resilience, springing back to shape after momentary finger tip compression. Winkelmeyer (2002) claims it is the polyester polyurethanes of the 1960s which are found to have disintegrated where the polyether polyurethane foams have often survived into the twenty-first century. The 2004 condition of the *Globe* supports at least the second half of this statement.

The foam is however altered from its likely original condition. Beneath the seat cushion the foam has been compressed. This compression is particularly visible at the front edge of the chair where the edges of the seat cushion meet the upholstery padding (Figure 58). The seat cushion was removed from the chair for a little over an hour during the first examination and for a period of more than 48 hours during the second. During this time no recovery of the original shape of the foam padding was observed. Beneath both cushions the foam is also firmer to the touch than it is anywhere else. It is possible this is due to the observed compression of the foam but may also be due to the softening of the rest of the foam, a possible result of degradation.



◄ Figure 58: The lower third of the *Globe* with the seat cushion removed. The tip of each arrow indicates the point where the compression in the shell pad foam is most visible. V & A – Circ. 12-1969 (Photo – J. Wickens)

With the foam in such relatively good condition the original supposition that the altered profile was the result of crumbling foam was determined to be most probably incorrect. It appears that it is a failure of the adhesive used to secure the top cover fabric to the foam that is the cause behind the distortion in the chair's profile. The adhesive bond between the foam pads and the shell also appears to be suffering degradative affects although to this point it has only weakened at the adjacent edges of each pad rather than ruptured completely. The bond at the centre of each pad is still quite secure.

The loose cushions are in a very robust condition. There are no signs of weakening in the stitched seams. The zip in both cushions functions smoothly. They are soft to the touch and are easily returned to their current shape if distorted during relocation. A clear distortion of shape was observed in the seat cushion when it was removed from the chair to facilitate the examination and documentation process (Figures 59 & 60). During the approximately 48 hours the cushion sat on a flat table surface before being returned to the chair it recovered some of what is presumed to be its original profile. This distortion appears to be the result of compression in the wadding layer of the cushion rather than the foam layer. It is possible more recovery could be achieved over a longer period of time or with the addition of physical manipulation.

▲ Figure 59: A rear view of the seat cushion showing distortion in the profile. V & A – Circ. 12-1969 (Photo – J. Wickens)

▲ Figure 60: The proper right side of the seat cushion showing distortion in the profile. V & A – Circ. 12-1969 (Photo – J. Wickens)

1.6 – Condition of other *Ball* chairs

The examinations previously described which revealed additional details about the construction of the *Globe* and *Ball* chairs in general also further expanded knowledge about the condition of the *Globe* and how its condition relates to that of other *Ball* chairs. Again, the 2CM pads were of primary importance in this regard.

An initial examination showed that generally the foam appeared to be in a condition quite similar to that previously documented in the *Globe*. In most areas it was not crumbling. When temporarily compressed it still sprung back. It had a layer of adhesive on the obverse surface which was still functional in areas likely to have been covered by a loose seat cushion. No longer functioning adhesive covered the rest of each pad.[49] These details coupled with the fact that spectra of both foam and adhesive had shown them to be in a similar condition to those in the *Globe* (Section 1.4) suggested that the results of a further investigation of their condition could be applied to a description of the condition of the *Globe*.

The top covers were removed from 2CM Pad 5 revealing that the still functional adhesive was creamy white in colour where the no longer functional portions were amber (Figure 61). Examination with a stereomicroscope revealed that the still functional adhesive covers the surface of the foam in a fibrous web-like structure. This structure then periodically expands into larger film-like areas which cover entire cells of the foam. The non-functional adhesive has lost the fibrous web and developed a crystalline appearance (Figures 62 & 63).

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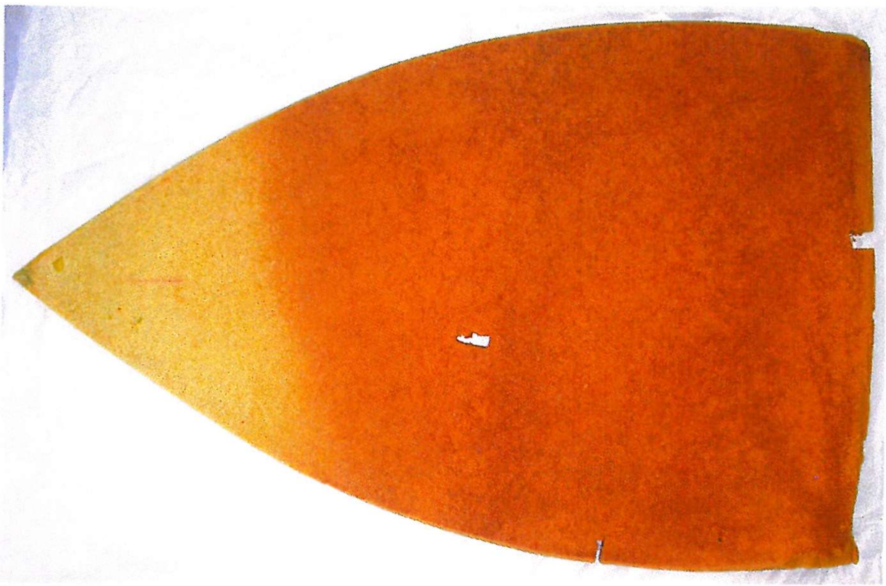
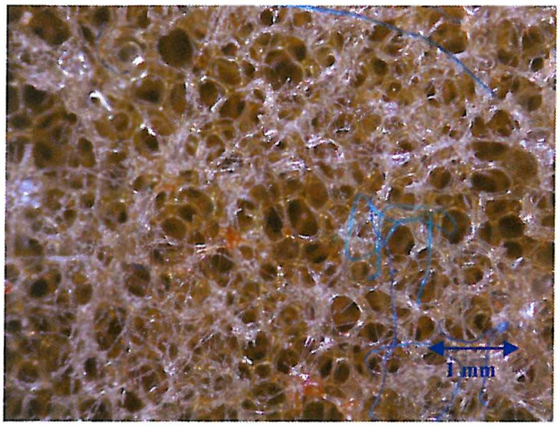
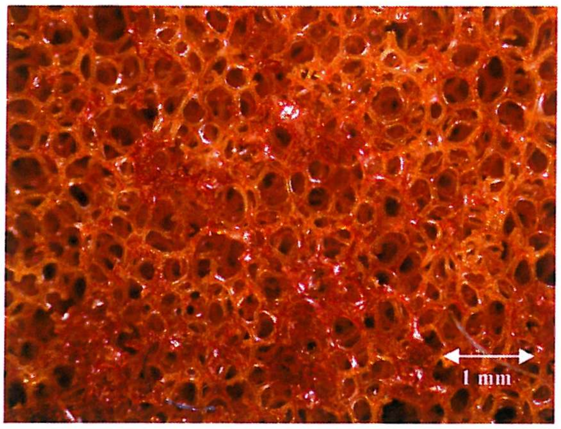
[49] There were some condition details of the 2CM pads which varied from those found in the *Globe*. There were at least two other adhesives in addition to the presumably original polychloroprene based adhesive on the reverse of the pad. There were several metal(?) pins in each pad which were assumed to have been used to try and re-secure the sagging top cover fabric to the foam pads. The edge of each pad which would have been located at the edge of the chair shell was in a fragile, crumbling condition. This was a likely result of the conditions in which they had been stored since they had been removed from the *Ball* they were used to upholster. However, as each one of these variations was localized and the majority of the conditions of the pads correlated well with those in the *Globe* they raised no significant concern.



◄ Figure 61: 2CM Pad 5 with the no longer functional, amber coloured adhesive on the right and the functional, creamy white adhesive on the left. (Photo – J. Wickens)

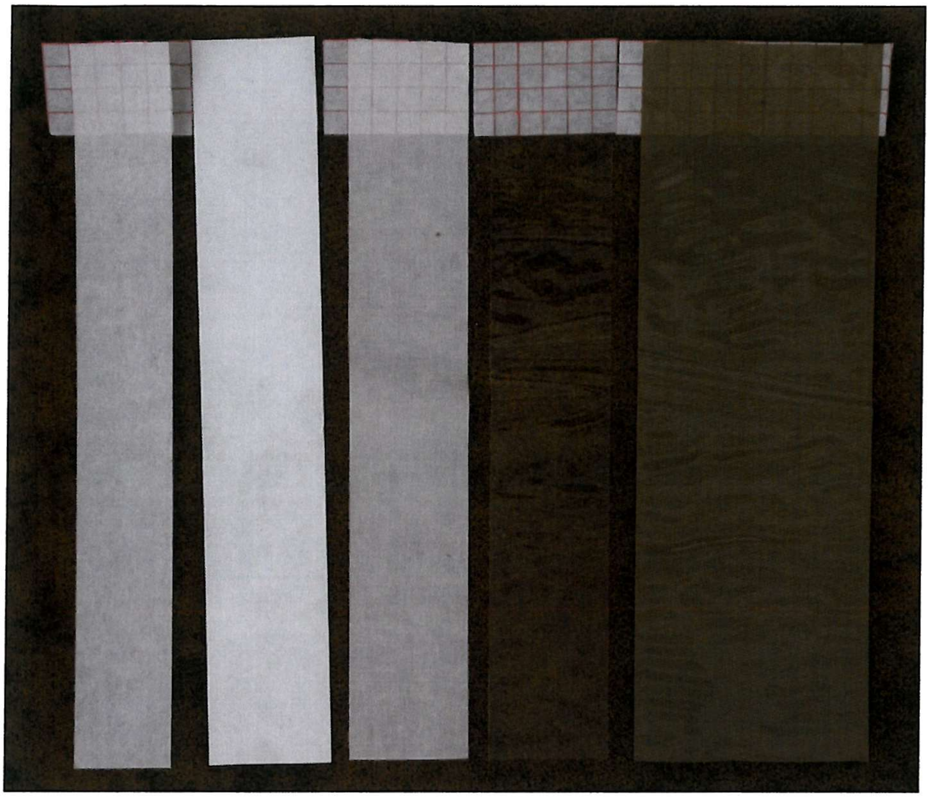


▲ Figure 62: A detail of 2CM Pad 5 showing the still functional adhesive with a fibrous web-like structure. (Photo – J. Wickens)



▲ Figure 63: A detail of 2CM Pad 4 showing the no longer functional adhesive with no more fibrous web and a crystalline appearance. (Photo – J. Wickens)

In order to determine, at a basic level, just how fragile the adhesive covered foam surface was, 150 mm lengths of five different types of self-adhesive tape were applied to an area of the foam with functional adhesive and an area where the adhesive coating was no longer functional. By trade name the tapes are Filmoplast P90, Tyvek Tape, Masking Tape, n2 by Guilbert and Scotch® Pressure Sensitive Tape by 3M. Common descriptions for them would be, in the previous order and that seen in Figure 64, paper tape, tyvek tape, masking tape, sellotape and packaging tape.



◄ **Figure 64: 150 mm lengths of self-adhesive tapes applied to the no longer functional adhesive surface of 2CM Pad 5. (Photo – J. Wickens)**

These tapes were left under the weight of a 6 mm thick glass plate for 24 hours and then removed. The relative amount of force needed to remove the tapes as well as a qualitative description of how much of the adhesive covered foam surface was removed by each tape was recorded. The same tape applied to the two different surfaces always removed more debris from the no longer functional surface. In no case however did the debris ever cover the entire surface of the tape. Each piece of debris was smaller than one cell of foam with a very occasional larger piece and it was either adhesive alone or adhesive covered foam (Figure 65). This indicated the foam is probably somewhat vulnerable to a depth of about 1.0 mm[50] and is just as likely to be the result of brittle, degrading adhesive as degrading foam.

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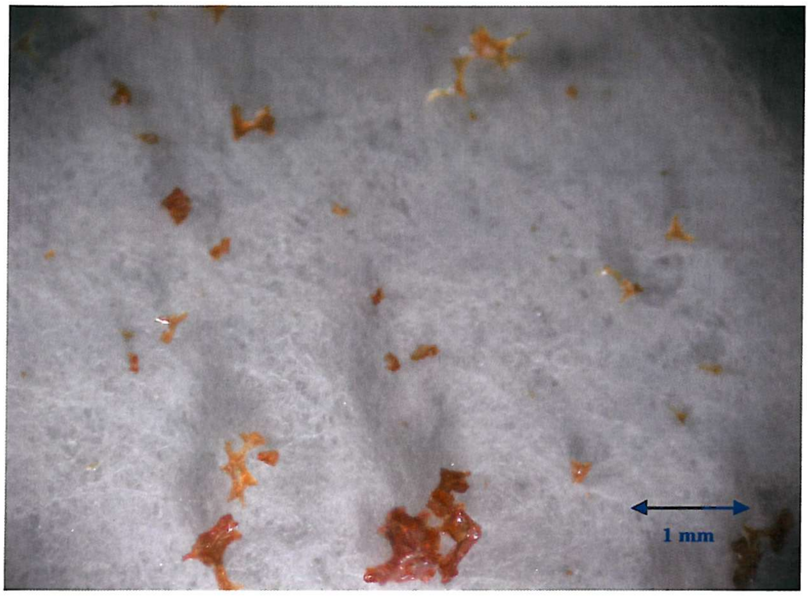
[50] The maximum diameter of a cell in the foam and twice as much as the maximum depth the adhesive was seen to penetrate.



◄ Figure 65: Some of the debris removed from the no longer functional adhesive surface by Filmoplast self-adhesive tape. (Photo – J. Wickens)

The pH of 2CM Pad 5 was evaluated in two general locations, one where the adhesive on the obverse was still functional and one where it was not. In each of these locations the pH was measured:

- on the adhesive covered obverse surface near the edge of the pad
- in the middle of the foam depth below the obverse surface evaluation
- on the adhesive free vertical surface adjacent to the obverse surface evaluation.

Fisherbrand pH-Fix 0-14 indicator strips were moistened with deionised water registering a pH of 7. These moistened strips were either laid against the foam in the area to be tested and covered with a 6 mm thick glass weight or inserted into a slit cut to gain access to the internal surfaces of the foam. The moist strip was left in place for five minutes (min) and then removed and compared to the control charts provided with the indicators. The results of this comparison are listed in Table 1.

Table 1: The pH of 2CM Pad 5 taken in six locations as listed.

General Location	**Specific Location**	**pH**
Still functional adhesive		
	Obverse surface	7-8
	Vertical surface	7-8
	Interior	7
No longer functional adhesive		
	Obverse surface	5-6
	Vertical surface	6-7
	Interior	7

Cross-sections of 2CM Pad 5 were cut from the locations where the pH determinations were made (Figures 66 & 67). They reveal that if the original colour of the foam was white to off-white then the foam beneath the no longer functional adhesive has undergone a greater colour change.[51] However they also indicate that there may not be a direct correlation between colour and pH as the pH of the interior of both samples was determined to be 7 and the colour of the interior of both samples is obviously not the same.

▲ Figure 66: A 5 cm by 4 cm cross-section of 2CM Pad 5 cut from the area beneath the still functional adhesive where the previously mentioned pH determinations were made. (Photo – J. Wickens)

▲ Figure 67: A 5 cm by 4 cm cross-section of 2CM Pad 5 cut from the area beneath the no longer functional adhesive where the previously mentioned pH determinations were made. (Photo – J. Wickens)

Images of a number of *Ball* chairs reveal that the distortion of original profile by sagging top cover fabric is not a condition specific to the *Globe*. The extent and location of the separation varies but there is no doubt the condition is something many of the chairs have in common. Only the 2CM pads and the *Globe* were examined closely enough in this project to determine that it is most likely adhesive failure that has caused the separation but it is presumed likely that such is the case in the three examples shown below (Figures 68 - 70).

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[51] Section 2.1.2 documents that unless the foam was pigmented during production its original colour would have been white to off-white.

▲ Figure 68: The sagging top cover in VDM – MSK-1001-2. (Photo – VDM)

▲ Figure 69: The sagging top cover in MMFA *Ball*, D87.245.1. (Photo – Fiell & Fiell 2002: 23)

▲ Figure 70: The sagging top cover in Sotheby's *Ball*, Lot 146, Sale L05814. (Photo – www.sothebys.com)

The chair with the red leather upholstery at the VDM, MSK-1001-1, did not exhibit any evidence of this condition. The orange woven wool covered chair, VDM - SSK-1002, showed top cover separation in a small area to the proper left of the bottom seat cushion but no where else on the chair. The lack of separation, in the first instance, was given little consideration. The chair is constructed and upholstered using a large number of variations on the methods and materials used in the *Globe*. Its likely date of manufacture and the originality of the upholstery are far from firm facts. Comparisons regarding the condition of the *Globe* and this chair might be able to be made but it would be like comparing apples to oranges and therefore not useful for the discussion here.

The condition of VDM - SSK-1002 warranted a bit more thought. The chair is upholstered in a fabric of identical weave and fibre content to that on the *Globe*. This fabric and a few other details place its likely manufacture to the Asko period of production and perhaps to the early years of the Asko period. If the date of production was similar why was the condition not as well? Certainly there are issues of use to consider for if one of them was heavily used and the other never sat upon the difference in condition might be easily explained. However, the *Globe* was shipped directly from the manufacturer to the V & A and was presumably never used.[52] What happened to VDM - SSK-1002 before it arrived at the museum is less clear. Thus if anything, one might expect that the VDM chair would be in worse condition than the *Globe*. As previously explained, it is likely that the *Globe* was part of a travelling exhibition during which the conditions could have been very variable. It has been displayed in a gallery with less than stable temperature and humidity.[53] Perhaps the VDM chair has only been exposed to stable conditions? Or, there is the possibility that the fabric has been re-adhered to the foam. In previous years the VDM had an upholsterer working on many objects in its collection and it was suggested that the *Ball* might have been one of the pieces on his project list. It could not be confirmed that this was so but if it was his standard operating procedure in a case like the *Ball* would have been to re-adhere fabric to an old or new understructure, depending on the condition of the original.[54] The stitching at the front edge of the chair and at the abutment of all five pads at the centre back seemed to contradict this possibility as it appeared to be original. However, it is possible the stitching is expertly applied re-stitching. If the chair had not been reupholstered repairing any lost bond perhaps the chair was produced at the later end of

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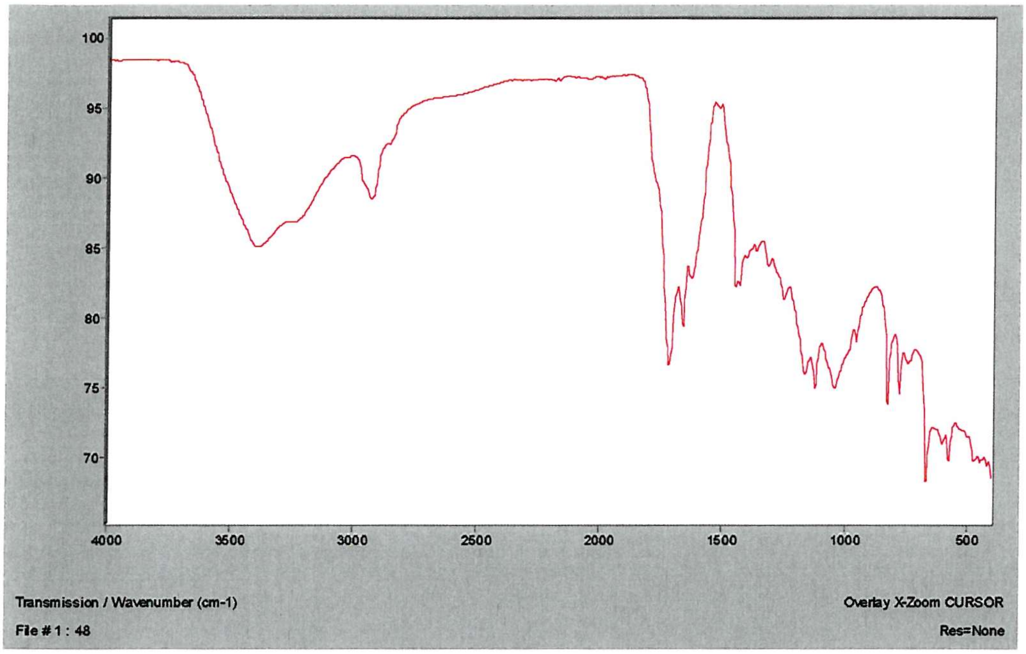
[52] This assumption was supported by Christopher Wilk, Keeper of Furniture, Textile and Fashion, V & A during an informal presentation of a portion of this work on 3 July 2007. The presentation was arranged by Dana Melchar, furniture conservator, for curators and conservators in the V & A furniture and textiles departments and given by the author.

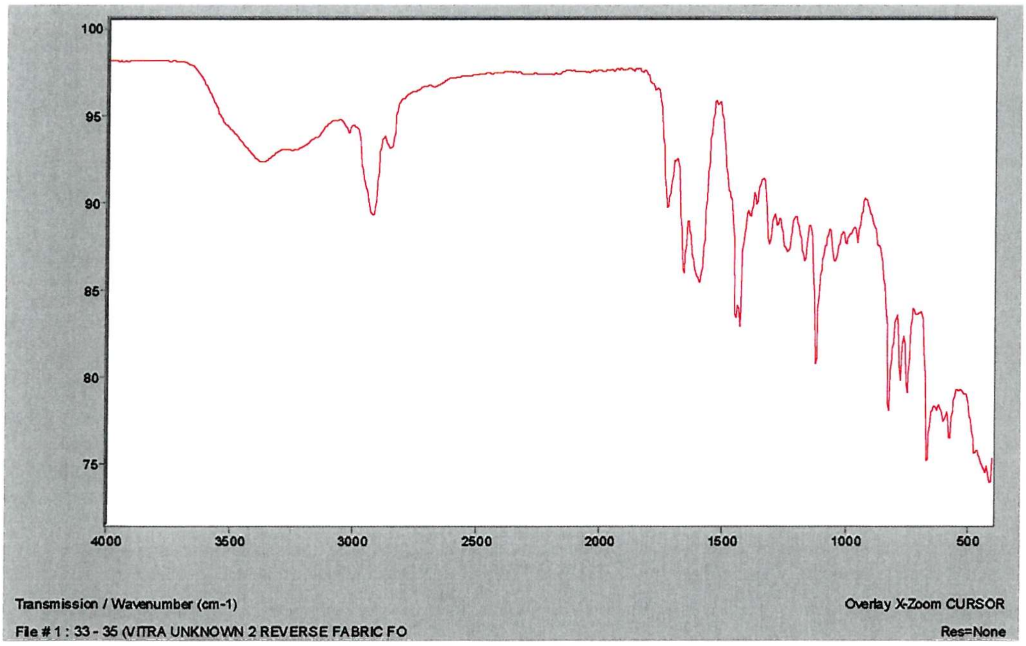
[53] As evidenced by a report provided by Louise Shannon, Curator, Furniture, Textile and Fashion, V & A giving environmental data for the Twentieth Century Study Galleries during the period 1 August 2004 to 19 January 2005

[54] Personal conversations with Kathrin Kessler, Conservator, AXA Art Conservation Project in cooperation with the Vitra Design Museum, 4-6 April 2005.

the Asko period with the same adhesive used in the *Globe* and the adhesive had only just begun to degrade. This would explain the loss of bond in the lower pad on the proper left of the chair although it is curious to note that if this is the case the first sign of degradation is in a lower rather than an upper pad. Or perhaps, the adhesive used to secure the fabric to the foam is original but of a different formulation than that used on the *Globe* and the formulation does not degrade in the same way or at the same speed as that used on the *Globe*. Due to the secure construction of the chair an adhesive sample from the obverse of one of the pads could not be obtained but a sample from the reverse edge of one of the pads could be. FTIR analysis of this adhesive as compared to that found in the *Globe* suggests they are similar adhesives but not exactly the same and thus perhaps this fact explains the difference in condition (Figures 71 & 72). Obviously, it is not clear why the top cover fabric in this chair still remains almost completely bonded to the underlying foam. What is clear is that it shows the condition of these chairs, even when manufactured with very similar materials, is not always the same.



▲ **Figure 71: FTIR spectrum of the degraded polychloroprene based adhesive on the obverse surface of the shell upholstery pads of the *Globe*. The sample was removed from the obverse of the proper left side pad.**



▲ **Figure 72: FTIR spectrum of the still functional adhesive used to secure fabric to foam on VDM – SSK-1002. The sample was removed from the reverse of the proper left side bottom cushion.**

The other noticeable difference between the condition of VDM - SSK-1002 and the *Globe* is that the outer layer of paint on the pedestal and mounting plate shows no evidence of cracking in the VDM chair. Thus it is not only the bond between the fabric and the foam that is in better condition in this chair.

The other *Ball* which exhibited significant differences in condition from those found in the *Globe* is the chair in the collection at the MMFA, D87.245.1. The image in Figure 69, Page 56 shows it degraded in a way that caused the fabric to separate from the underlying foam. This separation is further documented in the initial catalogue entry for the chair written after it was donated to the museum.[55] Today the situation is quite different. Most of the fabric is now adhered to the foam understructure and the foam has expanded in quite a few locations (Figure 73). It seems most likely that the change in condition is the result of some undocumented conservation work which was carried out on the chair in the 1990s. This work apparently involved efforts to clean the top cover fabric and re-adhere it to the underlying foam layer.[56] Perhaps the re-adhesion was successful but since the date of the conservation work the materials used in the process have caused the materials in the *Ball* to degrade in different ways.

◄ Figure 73: The *Ball* in the collection at the MMFA, showing its condition on 25 May 2004. Note the secure fabric but the altered profile due to expanding foam. MMFA – D87.245.1 (Photo – J. Wickens)

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[55] Date of entry 24 January 1988, photocopy of initial condition report supplied to the author by Diane Charbonneau, Curator of Non-Canadian Decorative Arts after 1960, MMFA

[56] Personal email communication with Diane Charbonneau, Curator of Non-Canadian Decorative Arts after 1960, MMFA, April 2004

1.7 – Conclusion

These details of history, construction and particularly condition make it clear that the primary issue related to the physical conservation of the *Globe* involves the materials used to upholster the shell of the object. The top cover fabric is no longer adhered to the foam beneath it. This change has altered the original profile of the chair and put stress on the fabric and foam. Surprisingly, the transformation is probably largely the result of the fact that the adhesive used to secure fabric to foam is no longer functional in most locations on the chair. The fact that the foam is at least slightly altered from its original condition may also contribute to the transformation. However, the changes related to the fabric, foam and adhesive are certainly not the only conservation issues for the chair. The paint on the pedestal is cracking and chipped. The hard shell of the chair is chipped and marked. There may be other alterations which are hidden by the upholstery.

It appears that there is a similar primary problem in other *Ball* chairs. This possibility offers the hope that a solution for the *Globe* could become a solution for more than one chair. Additionally, several of the problem chairs highlighted in the introduction to this work have been upholstered by adhering fabric to foam. The eventual conservation of any of these chairs will need to consider the adhesion of foam and fabric in some way. This reality again offers the possibility that a solution for the *Globe* could become a solution for more than one chair. However, the condition of other *Ball* chairs is not 100% identical to that of the *Globe*. Nor is the construction or condition of the other foam upholstered chairs previously mentioned. Therefore, a solution for the *Globe* would probably require alteration before it could be applied to one of these other chairs. However, even if significant alteration was necessary a solution for the *Globe* would at least offer foundational research on which to build the development of an alteration.

This identification of a specific primary conservation problem in the *Globe* at least some what related to conservation problems in other *Balls* and other twentieth century foam upholstered furniture narrowed the scope of the research. It defined the conservation issues related to the foam, fabric and adhesive in the shell upholstery as the subject of further investigation. At the same time it maintained the earlier offered hope that a solution for the *Globe*, even in the form of a solution for one conservation problem exhibited by it, would benefit other twentieth century foam upholstered objects.

This more narrow definition of the research almost completely removed the shell, pedestal or loose cushions from further consideration. The physical interface between the loose cushions and the shell upholstery and the shell upholstery and the shell itself had been thoroughly investigated during the object examinations previously described. Therefore these physical interfaces and any construction details of the *Globe* which proved relevant to any conservation plan for the shell upholstery would be considered. However, the work would not produce a conservation plan for the cracked, chipped paint on the *Globe's* pedestal. No plan for the marked, chipped shell would be devised. What to do with the altered profiles of the loose cushions would be largely unconsidered. It had not been possible to sample the pedestal paint or materials used to form the pedestal and shell of the *Globe* or any other *Ball* chair.[57] Therefore their chemical composition remained in question and any possible chemical interactions between the materials and the upholstery of the shell would not be considered. The elimination of these issues from further deliberation offered no reflection on whether they required attention. It was done because in the foam, fabric and adhesive used to upholster the shell of the *Globe* was found a specific example of a current conservation challenge for upholstery conservators. Therefore the search for a solution would focus on this challenge not the other peripheral issues which could be found in other materials in the *Globe*. This meant that questions about how to conserve the *Globe* would still remain at the conclusion of the project but it offered the hope that questions about how to conserve the shell upholstery would largely be answered.

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[57] Such sampling was determined by staff at the V & A, VDM and MMFA to be beyond the scope of the examinations of the *Ball* chairs in their care.

Chapter 2 – The *Globe's* Polyurethane, Wool and Polychloroprene: Their History, Structure and Degradation

With the narrowing of the research direction the flexible polyether polyurethane foam, wool fabric, and polychloroprene based adhesive used to originally upholster the Globe became the primary focus. Each of these materials is well documented in numerous literature sources.[58] *Here a brief historical context, the basic chemical composition, physical structure, and details of the primary processes and subsequent effects of degradation are presented for each material. The three materials are then carefully considered as they would have and do exist as a combination in the Globe. This analysis looks at how the materials relate to each other historically. It provides details about why the materials would have been an excellent choice for the original upholstery process in the Globe. It considers what has probably happened to make them no longer able to serve their original purpose. In this the physical qualities of the materials needing conservation, the strengths and weaknesses that would need to be considered in a conservation solution for them, become clear.*

2.1– Polyether polyurethane flexible foam

The foam used in the padding of the *Globe* shell and loose cushions and the foam used in the 2CM pads was identified as polyether polyurethane (Section 1.3.3). Polyether polyurethane foam was developed following World War II based on research carried out by Bayer beginning in 1937 and DuPont™ in 1938. It was introduced to the commercial market in the late 1950s by among others, The General Tire and Rubber Company. At the time the prediction was that it would be a material with wide spread applications in the fields of upholstery, automobiles, bedding, aircrafts, cushioning and insulation. By 1957 General Tire's version of it had found its way into 135 furniture lines some of which were mass produced and others which were exclusive, decorator pieces. In the following years it almost completely replaced the previous market leader in upholstery padding, latex foam rubber, and by 1997 it was identified as the well established cushioning material of choice for furniture manufacturers (Healey 1997; The General Tire and Rubber Company 1954-1958; van Oosten 1999).

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[58] For more details regarding polyurethane foams see Brydson 1999, Buist 1978, Buist & Gudgeon 1968 and Klempner & Sendijarevic 2004. For details of wool fibres and fabrics see Gohl & Vilensky 1983, Hatch 1993, and Tímár-Balázsy & Eastop 1998. For details of polychloroprenes see Fisher 1957 & Packham 2005.

Although polyether polyurethane foam has only been in use for about 50 years conservation literature identifies it as being present in several classes of objects currently in museums. It was used in art objects and TV puppets of the 1960s and 1970s. (de Jonge 1999; Rava et al 2004; Smith 2004). It has been used to make synthetic suede fabrics which have been used in clothing and upholstery (Kerr & Batcheller 1993). It has been found in upholstered chairs dating from the 1960s and 1970s (Kessler 2004; Vandenbrouck 2004) and it has apparently been used in the manufacture of *Ball* chairs from their introduction through to the current day (Section 1.4). No doubt, based on how extensively it has been and is used its presence in museums today is much more pervasive than this literature indicates and it will become even more so in the years to come.

2.1.1 – Chemical composition and physical structure

Polyurethane foams are the product of two primary reactions. A polyhydroxy compound reacts with a polyisocyanate to form a polyurethane. At the same time an isocyanate reacts with water to produce an amine and carbon dioxide (Figures 74 & 75). The first reaction produces the primary polymer building block for the foam. The second reaction produces the gas necessary to turn the basic liquid polymer into a foam (Brian Jones & Associates n.d.; Brydson 1999; Klempner & Sendijarevic 2004; van Oosten 1999).

$$\text{Polyhydroxy} + \text{Polyisocyanate} \rightarrow \text{Polyurethane}$$

$$HO(CH_2)_4OH + OCN(CH_2)_6NCO \rightarrow {\sim}O(CH_2)_4OOCNH(CH_2)_6NHCO{\sim}$$

▲ Figure 74: The basic chemical reaction involved in the formation of a polyurethane.

$$\text{Isocyanate} + \text{Water} \rightarrow \text{Carbamic Acid} \rightarrow \text{Amine} + \text{Carbon Dioxide}$$

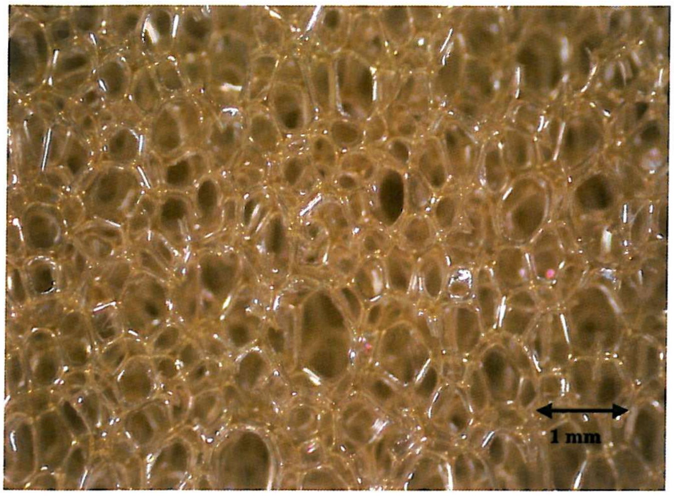
$$R\text{-}NCO + H_2O \rightarrow R\text{-}NHCOOH \rightarrow R\text{-}NH_2 + CO_2$$

▲ Figure 75: The basic chemical reaction involved in the production of the carbon dioxide gas which is necessary for foam formation.

In the 1960s, when the foam in the *Globe* and with all likelihood the 2CM pads would have been produced, the isocyanate most likely to have been used would have been toluene diisocyanate (TDI) 80/20, the isocyanate which dominated flexible foam manufacture at the time and in years to come. Its general chemical formula is $CH_3(C_6H_3)(NCO)_2$ and would have probably been supplied in an 80/20 blend of the two common isomers 2,4 and 2,6 diisocyanate although a 65/35 blend was also used at the time. The most widely used polyether, which would function as the polyhydroxy in the reaction above (Figure 74, Page 64) was polyoxypropylene triol. The fact that this polyhydroxy is a triol means it has more than two functional groups. The use of such a reactant meant that the end product was branched and/or cross-linked rather than linear like the product in Figure 74, Page 64 (Buist 1978; Buist & Gudgeon 1968; van Oosten 1999).

The method most likely to have been used in the manufacture of the foam is what is termed the one-shot method. The system would have been less than ten years old in the late 1960s. Before its introduction polyether polyurethanes had to be produced by first carrying out the polyurethane producing reaction with an excess of isocyanate. Then water, catalysts and other ingredients would be added in order to turn the polymer into a foam. The one-shot method made it possible to carry out both reactions simultaneously (Brydson 1999; Buist 1978; Buist & Gudgeon 1968).

The process involved preparing a formulation which was then mixed in a machine and poured onto a conveyor belt. As the required reactions took place minute bubbles were formed in the liquid. The bubbles would then slowly increase in size and as they did the foam would rise. If properly formulated the walls of the cells formed by the bubbles would rupture at the peak of the foam rise leaving a fine, intersecting structure of cell ribs (Figure 76). If improperly formulated large voids in the foam would result from the rupture of both cell walls and ribs (Klempner & Sendijarevic 2004).



◄ Figure 76: A detail of the intersecting structure of cell ribs which is left after the rupture of many of the cell walls during the final stages of foam formation. (Photo – J. Wickens)

The formula used in the process would have most likely included TDI 80/20, polyoxypropylene triol, water, catalysts (often including a tin compound), a non-ionic silicone-based surfactant, antioxidants and possibly a filler. The purpose of the first three ingredients has been described. A combination of catalysts would have been used to establish the proper balance between the polymer producing (polyisocyanate with polyhydroxy) and gas producing (isocyanate with water) reactions. The silicone surfactant's primary purpose would have been to stabilize the rising foam by reducing stress in the walls of the foam cells as they stretched and thinned. However, its inclusion would have also reduced the surface tension in the foam mix, emulsified incompatible ingredients and counteracted the defoaming effect of any solid ingredients. Antioxidants would have been included to stabilize the foam against degradation. If a filler was included its purpose would have been to increase the density of the final product or perhaps its load bearing and sound reducing abilities (Buist 1978; Buist & Gudgeon 1968; Klempner & Sendijarevic 2004).

The final product would have been a block of foam typically 100 cm high, 200 cm wide and continuous in length. It would have been, by volume, a network of interconnecting hollow spheres which was 2% to 3% polyether polyurethane polymer and 97% to 98% air. Due to the exothermic nature of the reactions involved it would have been quite hot, near 150 degrees Celsius (°C) as it came off the conveyor and only would have reached its fully cured state in the cooling process (Buist 1978; Buist & Gudgeon 1968). Once cured it would have been possible to cut these large blocks into the shapes required for the various pads in the *Globe*.

2.1.2 – Degradation

Common knowledge makes it clear that foams will become damaged and degraded from regular or harsh physical stress. A foam sponge used for washing the dishes is a perfect example. It is quite robust when first removed from its packaging but with repeated use it eventually becomes weak and begins to fall apart. Regular, repeated contact with any surface, not just dirty dishes, will eventually cause foam to split and crumble. A knife, a pair of scissors or many other sharp or pointed instruments can cut a piece out of it or slice right through it with little effort. There are however invisible processes which also cause the degradation of foams, including polyether polyurethane flexible foam.

Molecules like polyether polyurethane, which are not homogenous, have more stable and more reactive bonds. The reactive bonds are likely to interact with other molecules in their surroundings. In so doing the bonds can undergo changes in chemical composition or can split causing breaks in the polymer chain. Some of these reactive bonds or weak points on a polyether polyurethane molecule are the urethane (ROOCNHR'), ether (ROR') and amide (RCONR'R") linkages (Kerr & Batcheller 1993; van Oosten & Keune 1999).

The reactions which cause these changes in chemical composition and chain scission are oxidation and hydrolysis. Oxidation can be most broadly defined as a reaction in an organic compound that increases its content of any element more electronegative than carbon and thus involves a change in chemical composition. Hydrolysis is the cleavage of a molecule by water and thus involves chain scission (Solomons & Fryhle 2000). The reactive bonds in polyether polyurethane will vary in their resistance to these two reactions and it is thought that over all polyether polyurethane is more resistant to hydrolysis than oxidation (Kerr & Batcheller 1993; van Oosten & Keune 1999).

Both reactions are brought on by exposure to light, heat, and/or chemicals and are accelerated by the presence of moisture. Polyurethanes most sensitive to light exposure are those made from a polyether and an aromatic diisocyanate, the materials from which the *Globe* foam is most apt to be made. Exposure to both visible light and ultraviolet radiation causes both chain scission and crosslinking but eventually crosslinking will prevail. Heat has been shown to cause cleavage at the ether linkages in a polyurethane with the presence of oxygen as well as moisture accelerating the process. Additionally, heat tends to accelerate all degradative reactions. When new, polyurethanes are fairly resistant to many organic solvents but this resistance decreases as they age. However, exposure to highly polar solvents, acids and alkalis causes significant degradation and in some cases complete dissolution no matter what the condition of the foam (Kerr & Batcheller 1993; van Oosten 1999).

These degradative processes cause three primary overtly obvious physical changes in polyether polyurethane foam. The foam will be weakened so that it stretches and tears with greater ease. It will become brittle and eventually crumble even when no mechanical pressure is applied. It will change colour. If no pigment was added during the manufacturing process the original colour of the foam is likely to be white or off-white. Degradation will turn the foam yellow and eventually a dark yellow or almost brown shade (Kerr & Batcheller 1993; van Oosten 1999). Section 1.6 has documented that there is evidence of the last two in the 2CM pads and therefore most probably also in the *Globe* shell upholstery. The first is difficult to determine without information about the original condition of the foam with which to compare the current condition.

2.2– Wool fabric

The top cover fabric on both the *Globe* and the 2CM pads was identified as 100% wool (Sections 1.3.3 and 1.4). In contrast to the twentieth century introduction of polyether polyurethane foam, knowledge of wool can be linked to dates more than 100 centuries ago. The domestication of sheep has been dated to c. 9000 BC in the uplands of northern Iraq. The Law Code of Mammurabi lists wool as an export from Babylon c. 1800 BC. (McDowell 1993: 54). The processes of spinning wool fibres into yarn and then weaving the yarns into fabric can probably be dated to at least 5000 BC (Harris 1993). Wool in the form of fibres, yarns and cloth has been used for century upon century and is still a commonly used material in clothing, textile art and furnishing textiles today.

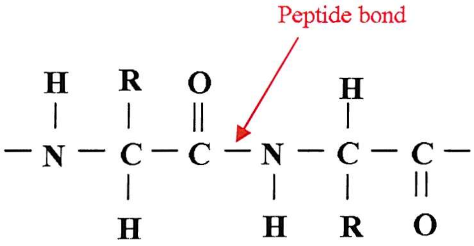
Its presence in museums and conservation literature is far too extensive to adequately document here. It can be found in collections related to ancient civilizations and twentieth century art. It is a material found in transport museums, historic houses and collections of ethnographic artefacts. Tapestries, clothing and upholstered objects often contain it. This pervasiveness means that the fact it was used as a top cover fabric in *Ball* chairs should not be surprising. Wool has been, is and will continue to be found in objects in historic collections.

2.2.1 – Chemical composition and physical structure

Wool fibres are protein based fibres built from the tiny, molecular structure of an amino acid. Individual amino acids are linked to each other in long chains and it is this long chain that forms a wool polymer. Three wool polymers spiral around each other to form a protofibril. Eleven protofibrils spiral around each other to form a microfibril. Hundreds of microfibrils are bundled together in a macrofibril and a number of macrofibrils are held together in a matrix to form corticular cells. Corticular cells are bundled together to form the cortex and it is this ultimate structure that forms the bulk of a wool fibre. The cortex is divided into two parts, an ortho-cortex and a para-cortex. The ortho-cortex is elastic and flexible. The para-cortex is stable and rigid. Within the cortex these two distinct divisions spiral around each other with the para-cortex generally on the inside. Surrounding the cortex is a relatively thin layer of cuticle cells.

As seen from the surface, these cells overlap giving the surface of a wool fibre a serrated look. The chemical properties of amino acids, the spiralling structure described above and the rough surface created by the cuticle cells give wool fibres their characteristics and are subsequently responsible for the way the fibres degrade (Gohl & Vilensky 1983; Hatch 1993; Tímár-Balázsy & Eastop 1998).

Amino acids have the basic formula $NH_2 - CH(R) - COOH$ where the R represents a different configuration of atoms depending on the amino acid being described. This R group is commonly referred to as the side group of the amino acid. The amino acids are linked together by peptide bonds (-CO-NH-) to form a long chain (Figure 77). This chain is in its most stable state if the amino acids wrap around each other placing the R groups, which are typically large, on the outside of the structure. This stable structure is helical in nature and known as α-keratin. A-keratin is composed of 18 different amino acids of which arginine, cystine and glutamic acid make up one third (Gohl & Vilensky 1983; Hatch 1993; Tímár-Balázsy & Eastop 1998).



$$-\overset{\mathrm{H}}{\overset{|}{\mathrm{N}}}-\underset{\underset{\mathrm{H}}{|}}{\overset{\mathrm{R}}{\overset{|}{\mathrm{C}}}}-\overset{\mathrm{O}}{\overset{\|}{\mathrm{C}}}-\underset{\underset{\mathrm{H}}{|}}{\mathrm{N}}-\underset{\underset{\mathrm{R}}{|}}{\overset{\mathrm{H}}{\overset{|}{\mathrm{C}}}}-\underset{\underset{\mathrm{O}}{\|}}{\mathrm{C}}-$$

▲ Figure 77: Two amino acids linked by a peptide bond (-CO-NH). Many more peptide bonds link many more amino acids to form a wool polymer.

The chemical complexity of the amino acid groups contributes to the fact that there are many different intra and inter polymer forces of attraction in operation in a wool fibre. The peptide bond linking the amino acids is quite polar. The oxygen of carbonyl groups (-CO-) will hydrogen bond with the hydrogen of the imino groups (-NH-). Salt linkages and ionic bonds will form between acidic and basic amino acid side groups. Covalent disulphide bonds form due to the sulphur-containing amino acid, cystine. These forces help to stabilize the helical α-keratin and the spiralling configuration of the overall structure of the fibre. Because of the strength of these bonds a wool polymer which is stretched out of its α-keratin configuration will typically attempt to return to this normal relaxed state. A wool fibre that is stretched to 10% more than its original length is likely to achieve at least 50% recovery, more than almost all other fibres (Gohl & Vilensky 1983; Hatch 1993; Tímár-Balázsy & Eastop 1998).

All the spiralling of polymers and cells within and around each other creates a fibre that is 25-30% crystalline and 75-70% amorphous. This combined with the presence of the polar bonds described above makes wool fibres very hydrophilic. They readily absorb water because the water is attracted by the polar bonds and can enter the fibre structure in the amorphous regions. This largely amorphous nature also makes individual wool fibres quite weak. This is perhaps counterintuitive following on from the discussion of the strength of the bonds in and between wool polymers. However, the lack of a significant proportion of rigid, crystalline regions in the fibre has much more influence on over all strength than molecular bonds (Gohl & Vilensky 1983; Hatch 1993).

When spun into yarns and woven into fabric the strength of wool becomes apparent again. This time however it is due to the length of the individual fibres, 50 mm to 350 mm, and the rough outer surface of each fibre created by the cuticle cells. These qualities prevent fibres slipping past each other with ease and thus once spun or woven into position they tend to stay there (Hatch 1993). This last characteristic can easily be seen to be a positive one for an upholstery fabric which would be expected to receive repeated mechanical stress from the actions of sitting down and standing up.

2.2.2 – Degradation

In the same way that changes to the chemical composition of a molecular bond or the cleavage of such a bond causes deterioration in polyether polyurethane these same processes cause deterioration in wool polymers and fibres. For wool, the weak points where these changes take place are the polar bonds, salt linkages, ionic bonds and covalent disulphide bonds which do so much to stabilize the structure in the first place. The reactions which induce these changes are brought on by exposure to light, moisture, heat, acids, alkalis, oxygen and pollutants, many of the same factors which induce change in polyurethanes (Gohl & Vilensky 1983; Tímár-Balázsy & Eastop 1998).

Wool exposed to ultraviolet radiation suffers the rupture of old disulphide cross-links and peptide bonds and the formation of new disulphide cross-links. Wool exposed to high levels of humidity suffers the rupture of hydrogen bonds and hydrolysis of salt linkages. This is due to the hydrophilic nature of the fibre. The peptide bonds and salt linkages attract water molecules which readily enter the amorphous regions of the wool fibres and as more and more water is absorbed the salt linkages become hydrolyzed and hydrogen bonds are forced apart. Heat will cause the rupture of disulphide and peptide bonds as well as the formation of new peptide bonds and in some cases the formation of ammonia and hydrogen sulphide. The pH at which wool keratin is most stable is in the region of 5-7. At this range the probability of chemical damage to the fibre is reduced and if damage occurs the extent of it is likely to be limited. If however the fibre is subjected to pH values below or above this region, degradative reactions take place. Of the two, wool is more resistant to acids than alkalis because acids leave the disulphide bonds in tact and alkalis do not (Gohl & Vilensky 1983; Tímár-Balázsy & Eastop 1998).

Thus exposure to all of these elements ruptures and/or alters the stabilizing bonds in wool polymers. Exposure to just one will weaken fibres leaving them more vulnerable to further degradation if exposed to another. The most visible result of degradation is fading or yellowing. When heat is the degradation inducing factor the discolouration will turn brown or black, signalling complete degradation, if the heat is not removed. Less visible results of degradation are the embrittlement, fragmentation and weakening of fibres and the release of hydrogen sulphide which can cause the corrosion of metals and the deterioration of other organic materials (Tímár-Balázsy & Eastop 1998).

Additionally wool fibres will degrade mechanically as a result of insect attack. The larvae of moths and beetles eat the keratin, an ingestible form of protein. Wool fibres, yarns and fabrics are obviously weakened by the process. These materials will also be weakened by repeated stretching and may eventually become permanently deformed. A wet wool fibre or fabric or an extremely dry and brittle one is more vulnerable to this last process than one maintained in an environment with a moderate humidity level (Gohl & Vilensky 1983; Hatch 1993; Tímár-Balázsy & Eastop 1998).

The most visible signs of degradation, fading and holes from insect attack, are clearly not present in the top cover fabric of the *Globe.* It is certainly possible that the fibres in the fabric are now more brittle than they were when the fabric was first applied but they have not become so brittle that they are shedding fibre fragments. In can certainly be imagined that the sagging of the fabric away from the upper pads may have induced some stretching in the fibres and the fabric. However, as Section 1.3.3 has documented it actually appears that the fabric would have to be slightly stretched if it were ever reapplied to the underlying foam which seems to indicate the fabric has probably not changed dimensionally. Overall, it appears the top cover fabric in the *Globe* has suffered very few of the degradative affects previously described leaving the fabric in a stable condition.

2.3– Polychloroprene based adhesives

The adhesive used to bond the wool fabric to the polyether polyurethane flexible foam in both the *Globe* and the 2CM pads was identified as a polychloroprene based adhesive (Section 1.3.3). Polychloroprene was the first mass produced synthetic rubber compound. It was introduced to the consumer market by DuPont™ in 1931 under the trade name Duprene® but is now called neoprene. It is highly elastic, like natural rubber, but more resistant to water, oils, heat and solvents. Since its introduction it has been widely used to bond elements of shoes, belts, automobiles, countertops, carpets, floor tiles and of course upholstery. In recent years it has been categorized as the most important class of rubber based adhesives (Allen 1984; Fisher 1957; Packham 2005; Wake 1976).

Conservation literature does not offer much with respect to its presence in museums or approaches to the conservation of objects which contain it. It was identified by Vandenbrouck (2004) as the adhesive used to adhere foam pads together in a *Locus Solus* chair, c. 1964, by Gae Aulenti which is currently in the collection at the Union Centrale des Arts Décoratifs, Paris. It has been identified in the *Globe* and in 2004 it was still used, in the form of Vertex K 400 by Kiilto Oy, to upholster *Ball* chairs.[59] It certainly must be present in other objects in other collections particularly when considering how widely it is used in industry. Shoes must contain it. Other upholstered items must contain it. It certainly must be present in transport collections. Within literature however it remains largely unidentified to this point.

2.3.1 – Chemical composition and physical structure

The chemical structure of polychloroprene is analogous to that of natural rubber with the methyl group of cis-1,4-polyisoprene having been replaced by a chlorine atom (Figure 78). There are in fact four different isomers of this molecule but the one shown is by far the most common (Comyn 1997; Packham 2004).

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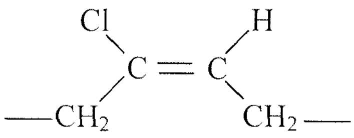
[59] Personal communication from Bert Ufermann, letter dated 25 May 2004 and email communication from Tero Mäkinen, Kiilto Oy, Tampere, Finland on 21 March 2005.



▲ Figure 78: The chemical structure of chloroprene, the basic unit which is linked to other chloroprenes to form polychloroprene.

It is this polymer which is used as the primary component when manufacturing a polychloroprene based adhesive but many other materials are added to improve the qualities and marketability of the product. Metal oxides of magnesium and zinc are added to retard the degradative affects of oxygen exposure as described below. Tackifiers are added to promote adhesion. Antioxidants slow the degradative reactions of polychloroprene with oxygen which are the reason for adding the metal oxides above. Solvents will be added to alter qualities of viscosity, development of bonding strength, open time[60], cost and ultimate strength. Curing agents are added to increase resistance to heat and although not often used other modifiers might be added to reduce crystallization rate, improve processability or improve adhesion to particular materials (Packham 2005).

During the manufacturing process polychloroprene polymers can be cross-linked to form a harder product. With natural rubber this cross-linking is achieved through vulcanization, an industrial process involving the use of sulphur and heat. With polychloroprenes the process is achieved through reactions involving the labile chlorine atom. One such reaction employs 4 parts of a light calcined magnesia and 5 parts of zinc oxide which removes the chlorine atoms and the polymers become crosslinked (Fisher 1957).

Because of the highly polar nature of the C-Cl bond, polychloroprenes bond to most highly polar surfaces and many surfaces with low polarity. They can in fact be used to bond almost any two surfaces together. They are generally used as contact adhesives, are commonly used as such in the upholstery field and were probably used in such a way in the *Globe*. This means the adhesive is applied to the surface of both adherends,

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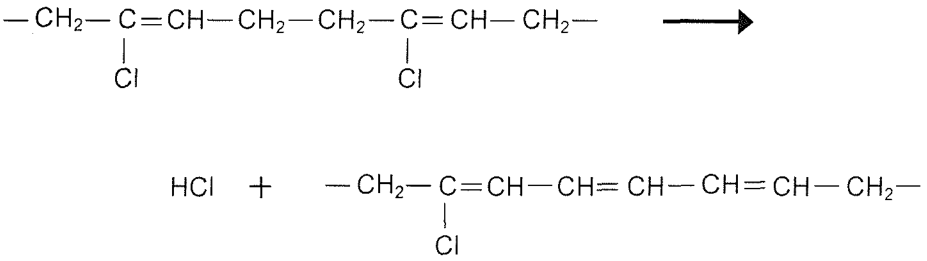
[60] Open time is the amount of time two adhesive coated surfaces can be unjoined before they will no longer bond once brought together (Chaudhury & Pocius 2002)

solvent is allowed to evaporate and then the two surfaces are brought together to form a bond. Because they have a relatively high crystallization rate they develop bond strength quite quickly. This allows the formation of an immediate dry bond between two surfaces without the use of clamps, no doubt a desirable quality when upholstering a fair number of objects at the same time (Comyn 1997; Packham 2005).

2.3.2 – Degradation

The primary degradative process for a polychloroprene involves once again a reaction with oxygen. This one is activated by light but will take place in the dark. It is also greatly accelerated by the presence of chlorinated rubber, a modifier sometimes added to a polychloroprene formulation to improve load bearing capacity. The result is the release of hydrogen chloride (Figure 79). Hydrogen chloride will then attack the adhesive itself and is a threat to any metallic elements in close proximity (Comyn 1997; Fisher 1957; Wake 1976; Wypych 2003).



$$-CH_2-\underset{\mathrm{Cl}}{\mathrm{C}}=CH-CH_2-CH_2-\underset{\mathrm{Cl}}{\mathrm{C}}=CH-CH_2- \longrightarrow$$

$$HCl + -CH_2-\underset{\mathrm{Cl}}{\mathrm{C}}=CH-CH=CH-CH=CH-CH_2-$$

▲ Figure 79: The reaction involving the release of hydrogen chloride which takes place during the degradation of polychloroprene.

The antioxidants mentioned above are included in the formulation of polychloroprenes to retard the progression of this degradative reaction. The metal oxides are included to combat the affects of this reaction at the other end. They consume the acid which is liberated in the degradation process (Packham 2005; Wake 1976).

The physical result of this degradative process is a weakening of the bonds between polymer chains in the adhesive. In turn this weakens the adhesive making it less effective (Wake 1976; Wypych 2003). The adhesive used to secure fabric to foam in the

Globe is clearly in a weakened, less effective state. In fact it is generally so weak it is no longer functional. Of the three materials just described it is the material that has most clearly degraded exhibiting the effects literature describes will present themselves.

2.4– The three in combination

When considered in combination rather than as separate materials and within the context of how they were used in the specific object of the *Globe*, small details regarding their place in history become apparent. It becomes clear why the three materials would have been used to produce what needed to be a very durable bond. Reasons for why such a bond would no longer be functional can be proposed.

2.4.1 – Historical implications

The details above suggest that the polyether polyurethane foam used in the *Globe* is a fairly early example of the material. When considered within the context of polyether polyurethane foams used in Finland this may be even more true. It has been offered that foam rubber was the primary foam used in Finnish furniture from 1956 to 1966.[61] As the *Globe* dates to 1968 the use of polyether polyurethane foam in its upholstery may be one of the earlier examples of such use in Finland. There is no evidence that similar claims can be made for the polychloroprene adhesive and obviously no such claim could be made about the wool fabric. However, the claim probably can be made with respect to the three being used in combination. The date of introduction of the foam makes it impossible for the combination to have been used more than a decade earlier anywhere in the world.

On the other end of the timeline, it appears the 100% wool upholstery fabric is an example of something that will only become rarer and rarer. The majority of wholesale and retail upholstery fabrics today are produced with at least a small synthetic component to improve both durability and fire retardency. The search for a similar fabric to that on the *Globe* yielded nothing available commercially that was 100% wool and as coarsely woven.[62]

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[61] Information recorded by the author at *The Forgotten History – Upholstery Conservation*, 12-13 May 2004 during the presentation 'Foam rubber and its effects on the textile parts of the chair' given by Kirsi Rumbin. The conference was organized by the Carl Malmsten Center of Wood Technology & Design and Birgitta Forum, the Faculty of Arts and Sciences at Linköping University, Sweden.

[62] The search included retail establishments like C & H Fabrics, Winchester, the suppliers for upholstery workshops like Bruce Upholstery (www.bruceupholstery.co.uk), Harris Design (http://www.charris-son.co.uk/) and People Like Us (http://www.visitwinchester.co.uk/site/things-to-do/shopping/parchment-street/people-like-us-p192951) and wholesale establishments like Whaleys (http://www.whaleys-

2.4.2 – A strong initial bond

Chemically, the details above make it clear why polychloroprene adhesive would have made a good choice for bonding polyether polyurethane foam to wool fabric. Polychloroprenes bond well to highly polar surfaces (Packham 2005). Polyether polyurethanes are highly polar due to the presence of urethane groups and they have a strong tendency to hydrogen bond (Buist & Gudgeon 1968). Wool is also quite polar due to its peptide bonds and other bonds within individual amino acids (Gohl & Vilensky 1983). The polarity of the three in combination would make them strong candidates for being able to establish stable chemical bonds with each other.

The reason these three materials were good candidates for adhesive bonding also has a mechanical component. As a woven fabric, the crimped nature of wool fibres causes their ends to project above the material's surface (Gohl & Vilensky 1983). These fibre ends then give an adhesive something to physically lock around and this characteristic would have a great influence on the ability of an adhesive to stick to wool (Wake 1976). The exact physical structure of a polyether polyurethane foam surface is in no way identical to wool. However the cells of the foam which would be cut through when shaping manufactured foam blocks to size would give a different although equally uneven surface onto which an adhesive could lock. Thus the surface structure of the foam and wool would make it possible for a strong bond between each surface and the polychloroprene adhesive to be established. This in turn would lock the foam and fabric firmly together.

2.4.3 – A non-existent bond today

However, even though it seems likely that a strong bond would have been established between the three materials when the *Globe* was manufactured in 1968 the above information offers a few possibilities for why the bond between the three has now failed. The bond has failed on all surfaces not covered by the loose cushions and along the bottom front edge of the chair beneath these cushions. In these areas the condition of the 2CM pads suggests that the foam in the *Globe* is fragile at the very surface but not weak and crumbling throughout. The adhesive is no longer soft and elastic but rather

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bradford.ltd.uk/) and Kvadrat (http://www.kvadrat.co.uk/). 100% wool fabrics of a finer weave were available but nothing as course as that found on the *Globe*.

hard and brittle. In addition its fine web-like structure has disappeared leaving small regular gaps in the coverage of the adhesive. In the areas beneath the loose cushions where the bond has not yet failed the 2CM pads indicate that the foam and adhesive are still in quite good condition. The fabric shows no obvious signs of degradation in either location. Something has happened to protect the bond beneath the loose cushions and it seems most probable that what has happened is the loose cushions have shielded the materials beneath them from a certain amount of exposure to oxygen. In turn this protection has slowed the degradative reactions described above and the bond has remained in tact.

Consideration was given to whether the protective function of the loose cushions was mechanical rather than chemical. It seemed possible that the mass of the top cover fabric pulling on the bond on the upper surfaces of the chair could have slowly pulled the adhered surfaces apart. However such a supposition does not explain why the two surfaces on the lower pads of the chair are no longer adhered as the fabric would not have physically strained the bond in these areas. It is possible that once the bond between the surfaces was weakened this mechanical stress might have accelerated separation in some areas but it is not likely this type of mechanical stress is the primary source of bond failure.

Consideration was also given to whether the loose cushions were protecting the underlying materials more from light exposure than oxygen exposure. However, the construction of the chair shields much of the interior surfaces of the shell from light exposure in the first place. The dense top cover fabric adds an additional layer of protection for the foam and adhesive. Recent display in the dimly lit Twentieth Century Study Galleries would have offered further protection from such exposure, at least in recent years. There was no sign that the fabric not shielded by the loose cushions was faded or more brittle than the fabric covered by them. Thus degradation initiated by exposure to visible light and ultraviolet radiation was not likely to be the primary source causing the separation.

There were two other possible sources of degradation which were eliminated in part because it was presumed there was no possibility the loose cushions would have protected the underlying materials from their affects. The first was mechanical stress due to use. If used enough to induce damage the loose cushions and the areas under them would certainly have received equal if not more stress than the areas showing degradation. The second was exposure to excessive heat. Although not likely, if the chair was exposed to a hot environment for a period of time long enough to induce degradation the heat would certainly be able to permeate the loose cushions and affect the areas beneath them.

From the details above this left oxygen, chemical exposure and moisture as possible sources of the degradation.[63] It is hypothesized that oxygen exposure is likely to be the primary cause of degradation. As some of the reactions oxygen exposure would induce release acids it is assumed acids have at least exacerbated the problem. The likely presence of enough moisture to accelerate and/or exacerbate degradation is unclear.

Given time and no accelerating conditions oxygen exposure will degrade polyether polyurethane and polychloroprene. Wool will degrade as well but at a slower rate. The examination of the *Globe* and the 2CM pads indicated that the wool was showing no obvious signs of degradation and the foam and adhesive not covered by the loose cushions were. Physically, the condition of the *Globe* shows signs that would be consistent with materials degrading primarily from oxygen exposure.

As it has been explained, polychloroprene, when exposed to oxygen, degrades primarily by giving off hydrogen chloride. This acid further degrades the adhesive and can attack the materials surrounding it. The process can be slowed by the use of antioxidants and the affects of the process can be reduced by the use of acid absorbers but it is not entirely eliminated. If oxygen was inducing the degradation process then the release of hydrogen chloride was taking place. The fact that the degraded adhesive surface was analyzed at pH 5-6 and that of the still functional adhesive surface was pH 7-8 may be additional evidence that the process had taken place in the areas not covered by the loose cushions and acidic evidence had been left behind.

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[63] It is also possible that a finish applied to the top cover fabric at some stage in its manufacture has played a role in the degradation but as no information regarding such a finish was acquired the possibility is not considered here.

The role moisture might have played in these degradation processes is perhaps the most difficult to hypothesize. The generally controlled environment in which the *Globe* was maintained, inside away from elements in a country with a moderate climate, seemed to greatly reduce the likelihood that excessive moisture would have been present in the first place. However, the fact that the chair might have been part of a travelling exhibition in the early 1970s and was recently displayed in a gallery with localized moisture problems and fluctuating humidity levels[64] did not eliminate it completely. Water absorbed into a bond line will weaken it (Packham 2005). Would the hydrophilic nature of the wool top cover fabric have caused enough water absorption from the surrounding atmosphere to weaken the bond between fabric and adhesive?

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[64] Personal conversation with Louise Shannon, Curator, Furniture, Textiles and Fashion, V & A on 12 May 2004

2.5 - Conclusion

It is likely that the reason the fabric is no longer adhered to the underlying foam in the *Globe* is that oxygen, and perhaps other agents, have induced degradative reactions in the polyether polyurethane, wool and polychloroprene used to upholster it. The reactions would weaken all three materials but have probably caused the most change in the polychloroprene adhesive, followed by the foam and then followed by the wool fabric. The induced changes have made the adhesive less effective and the foam and perhaps the fabric have become at least a bit brittle. This brittleness has caused the rough surfaces to which the adhesive was initially so well bonded to fragment giving a less effective adhesive a less than ideal surface to which to adhere. Bond failure has been the result.

In developing a conservation solution for these materials the current condition of the materials would obviously need to be considered. The fabric appears to be in good condition and could probably be expected to perform much of the function for which it was originally intended. The foam appears to be fragile at least at the surface and it would therefore probably need to be protected at least to some extent. The adhesive across the majority of the surface on which it was used is no longer functional. At the very most it can be hoped it will simply stay where it is.

In addition to the current condition of the materials what is likely to happen to the materials as time passes from the present day would need to be considered. It should be clear the materials are going to continue to degrade. If oxygen is the primary initiator of the problem the problem is not going to go away. Chain scission and cross-linking will take place. Degradation products will be given off. The adhesive is likely to eventually loose its functionality in the areas behind and beneath the loose cushions. It is also possible that fragments of degraded adhesive will begin to separate from the foam and fabric to which it is currently secured. The foam will eventually become more brittle and begin to crumble. In all likelihood, someday it will be for all intents and purposes completely gone. The fabric will some day reach a point where it is brittle as well. The affect of the materials underneath might mean that day is not too far away but it is likely that of the three materials the wool fabric will be in good condition for the longest amount of time. With this set of circumstances what can be done for the *Globe*?

Chapter 3 – Defining a Conservation Approach

Here, five possible approaches to the conservation of the Globe are summarized and validated by setting them within the context of previous work carried out in a variety of fields of conservation. A discussion of the significant facets of the general class of twentieth century furniture and the specific object of the Globe follows. The presented conservation approaches are then evaluated for their ability to conserve the Globe in a way that will serve the needs of the current and future users of it with the conservation of the identified significant facets being part of what would be required. The end result is the selection of one approach as theoretically most ideal. The goals of the selected approach and some of the unknowns related to its practical application are finally defined in more detail providing a starting point for the experimental portion of the research.

3.1– Five conservation possibilities

The details which have been presented in Chapters 1 and 2 were carefully considered. Previous work carried out with respect to the conservation of the materials in question was reviewed. Past and current practices in the fields of upholstery and textile conservation were examined. The result was the identification of five general approaches to the conservation of the *Globe* which were likely to be both ethical and physically possible. The pros and cons of each approach are numerous and diverse. When compared in very broad terms, two would make no attempt to restore the original profile of the chair. Three would do so making different compromises with respect to the materials and techniques employed in the chair's construction. One would restore the profile using a method which would also indicate what technique was used to originally upholster the chair. One would restore the profile without releasing any elements of original construction. Two would require the temporary release of original stitching. One would remove the original polyether polyurethane foam. In order to implement them, four of the five would require investigations of possible adaptations of established conservation techniques. One would require no physical conservation but significant amounts of research and documentation. When considered more specifically each approach reveals more pros and cons as outlined below.

3.1.1 – ***Do nothing***[65]

The simplest approach would be to do absolutely nothing to the chair. It could be accepted that part of the nature of some of the materials with which the *Globe* is constructed is that they degrade faster than many other materials. This speed of degradation means that even with the best of care in some cases they will change on a macroscopic, microscopic and submicroscopic level in a matter of years. These changes, while the kind of thing that conservation typically masks and seeks to slow or halt, could be embraced as part of the 'true nature'[66] of the chair and the chair could be left to get on with its degradation process.

Or it could be accepted that the conservation of twentieth century synthetic materials is still risky business. There have been conferences and subsequent publications where the subject has been the primary focus.

- *Saving the Twentieth Century: The Conservation of Modern Materials* (Grattan 1993)
- *Mortality Immortality? The Legacy of 20th-Century Art* (Corzo 1999)
- *Modern Art: Who Cares? An Interdisciplinary Research Project and an International Symposium on the Conservation of Modern and Contemporary Art* (Hummelen & Sillé 1999)
- *Modern Art, New Museums, Contributions to the Bilbao Congress* (Roy & Smith 2004)
- *The Future of The 20th Century. Collecting, Interpreting and Conserving Modern Materials* (Rogerson & Garside 2006)

The art insurer, AXA Art, has sponsored projects in an effort to one day find solutions for art objects and collectibles now considered unsalvageable. One of these projects, the AXA Art Conservation Project in cooperation with the Vitra Design Museum is specifically focused on the issues of degrading twentieth century synthetic materials including polyurethane foam (Vitra Design Museum n.d.). Numerous other individuals and institutions have carried out small and large projects in an effort to find ways to conserve twentieth century synthetics. Evidence of this work can be found in the bibliography of this volume and searches through AATA Online, Abstracts of

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[65] The title used to identify each approach will be underlined each time it appears in the text throughout this document. This is done to help identify it as a reference to a particular conservation approach.

[66] For a concise discussion of this well established conservation concept see Eastop (2006)

International Conservation Literature[67] and BCIN, the Bibliographic Database for the Conservation Information Network[68], two of the primary conservation publication databases. However, even with all this work there are still no clear answers for many materials. It is very possible that if interventively conserved, the *Globe* will some day develop the type of problems now seen in the MMFA's *Ball* or other equally troubling challenges. While no longer in its original condition, the *Globe* is not crumbling, sticky, cracking, shattering. It has not developed many of the more troubling qualities found in other degrading twentieth century furniture and design objects. Perhaps for the time being it should just be left alone.

Whatever the motivation there are plenty of examples which show that at some level this approach is not unknown to the conservation world. At the Brighton Museum & Art Gallery, in February 2004, there were two foam upholstered chairs from the 1960s on display. The foam in both was quite brittle and thus degrading but at the time there was no stated intention to conserve them by interventive methods.[69] In the 1980s, two other chairs purchased for the same exhibition that motivated the purchase of the *Globe*, were moved out of the V & A's Twentieth Century Galleries, into storage and no longer displayed due to their state of deterioration, *Sacco,* (Circ. 73-1970) designed by Piero Gatti, Casare Paolini and Franco Teodoro in 1968 and *Blow*, (Circ. 100-1970) designed by Gionatan de Pas, Donato D'Urbino, Paolo Lomazzi and Carla Scolari in 1967 (Griffith 1996). In the 1990s *59-18*, a polyurethane foam modern art piece created by Henk Peeters in 1959, was, due to its degrading condition, placed in permanent storage in the care of the Netherlands Institute for Cultural Heritage. The piece is expected to be in such a degraded condition the next time the storage facility is 'cleaned' it will be discarded (Rodrigo & Beerkens 1999). Gill (1990a) suggests that in extraordinary situations when this approach is the best that can be done a file of documentation be prepared that would include a full set of photographs of the object in question, designer's notes and drawings, and manufacturer's production specifications which would all seek to illustrate the original intention of the designer. Admittedly, none of these examples openly embrace the idea of accepting the 'true nature' of rapidly degrading twentieth century synthetic materials. Perhaps they are motivated by a desire

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[67] http://aata.getty.edu/nps/

[68] http://www.bcin.ca/

[69] Personal communication from Stella Beddoe, Keeper of Decorative Art, The Royal Pavilion, Libraries & Museums, Brighton, England, 13 February 2004.

to avoid intervention in order to not make things worse. Some of them are certainly grounded in the fact that knowledge does not currently offer a solution. What they do all show however is an acceptance for a process of displaying, storing and then discarding objects based on the condition of the materials from which they are made.

If applied to the *Globe*, beginning in May 2004, this might mean that it would be left on display with no effort having been made to alter its appearance. The top cover fabric would still drape away from the foam on the upper surface of the shell. The cracked and peeling paint would not be touched. Perhaps the marks and dust would be cleaned away as they are not deteriorating original materials but rather new additions to the object. But equally they might be left untouched as evidence of use and life since creation of the chair in 1968. In the following months and years the condition of the chair would no doubt deteriorate and eventually, perhaps not so far into the future, it is likely a decision would be made that the chair was no longer suitable for display purposes other than perhaps those involving the communication of the fragility of the materials it contains. At this stage perhaps it would be moved to permanent storage. It would be made available to researchers and it would remain as physical evidence of its existence but it would no longer be an object available to the general public. During its period of storage it would be fully documented as described above.[70] The accumulated file of documentation might also include a record of historical opinions about the impact of the chair and a set of results from a full scientific analysis of all existing materials in the chair. The file of documentation would be of great assistance to researchers 'using' the *Globe* during its period of permanent storage but it would also serve as a surrogate object when the chair was finally identified as no longer worthy of the space it occupied in the stores and it was de-accessioned and discarded[71] or, as suggested by van Oosten (1999), donated to science.

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[70] Such an effort would support, in retrospect, the most recently drafted collecting policy at the V & A. Generally the policy calls for a 'renewed focus on the history, provenance and individual quality of a specific object, and a greater stress on their documentation.' More specifically, the 'Contemporary Collecting Strategy' calls for the collection of a wide range of supporting material, 'including for example, design drawings, models, prototypes and materials samples, recorded interviews with the artist, craftsperson, designer or company, corporate literature, trade catalogues, information on the manufacture and dissemination of products, market research, point of sale material' when a finished product is collected (Victoria and Albert Museum 2004: 7 & 45).

[71] The step would be supported by the current acquisition and disposal policy at the V & A (Victoria and Albert Museum 2004: 48).

The approach would not conserve the *Globe* in the traditional sense of the word but it would conserve the fragile nature of some of the materials in it by not masking the fact that they have changed over time. In some cases this would mean displaying evidence that the materials have lost the ability to perform the function for which they were originally intended. It would conserve the *Globe* by making it available for study for as long as possible and in the end it would conserve the *Globe* by making sure evidence of as many aspects of its existence as possible was recorded for posterity.

*3.1.2 – **Slow degradation** through a change in storage or display conditions*

The second approach which, like the first, would make no attempt to restore the chair's original profile would be to slow the degradation of the materials in it using only means external to the chair. This would theoretically preserve the chair for a longer period of time in a similar or better condition than the first option.

Shashoua (1999) has shown that storing rubber objects in virtually oxygen free environments slows the degradation of the objects. This is evidenced by no observable change in tested objects over a period of 42 months. Griffith (1997) recommends an oxygen free environment as a way of prolonging the life of *Sacco* (Section 3.1.1) and *Armadillo*, designed by Designers Associated Milan in 1969, another twentieth century chair in the collection at the V & A, both of which are at least partially constructed of polyurethane. Winkelmeyer (2002) recommends the same for *Funburn* by John Chamberlain, c. 1967, a large polyurethane foam art object in the Museum für Moderne Kunst, Frankfurt/Main. She specifically recommends that a tent of ESCAL™ barrier film be built for the object and, through the use of oxygen absorbers, an environment of less than 1% oxygen be maintained inside the tent. Kozloski (1988) explains that a collection of spacesuits, in the care of the National Air and Space Museum, Washington, DC, and constructed in whole or in part of rubber and plastic is kept in a cold storage facility in order to slow the process of degradation in these objects.

Each of these conservation approaches is grounded in the previously explained facts that polyurethanes, polychloroprenes and wool degrade by exposure to heat, oxygen, light, ultraviolet radiation and moisture (Chapter 2). A simple extrapolation of these facts makes it possible to conclude that limiting exposure to any one or all of these elements is likely to slow or halt the degradation of the materials in question. Based on this principle, cool, dark, and/or oxygen free environments have been identified as candidates for slowing the degradation, of among other materials, natural and synthetic rubbers, polyurethanes and wools (Blank 1990; France 2003; Grattan 1988; Kerr & Batcheller 1993; Shashoua 1999) with the examples cited in the previous paragraph being real life applications of these suggestions.

Clearly, finding a way to create a cool, dark or oxygen free environment for the *Globe* would involve encasing it and/or turning out the lights. Either option would have implications regarding making the *Globe* suitable for display and the feasibility of any efforts to do so. An object in the dark can not be seen. A temperature and humidity controlled or oxygen free display case large enough for the *Globe* has great potential to be prohibitively expensive. Even if such an expense was deemed appropriate it is easy to imagine than an already visually altered design object subsequently encased in some type of chamber would lose the ability to communicate much beyond that of an obviously fragile object about to die. For these reasons, this second option probably only becomes reasonable for objects in storage. Objects can be stored in the dark. Oxygen free environments which do not have to be aesthetically pleasing would most likely be less expensive. What an object can communicate in its stored environment is not generally of concern. An encased *Globe* would likely become less available to researchers due to more limited access resulting from the encasement, an aspect of the approach which would most probably be considered a negative by some. However, an object with a longer life expectancy might be an acceptable trade off.

3.1.3 – ***Support without intervention***

The third option is the first that would attempt to restore the original profile of the chair and was suggested by Jan Vouri, Janet Wagner and Renée Dancause of the Canadian Conservation Institute (CCI).[72] The approach would involve fashioning an external support for the *Globe* chair fabric. The support would fit inside the shell of the chair and

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[72] The idea was generated during a research visit to the Institute, 10 June 2004, where the challenges the *Globe* presents were discussed with these conservators and conservation scientists Scott Williams and David Grattan.

press the fabric back against all surfaces of the foam understructure. If it were clear and rigid the fabric would still be visible through the support and it would theoretically function without the need for any stitched or adhered elements.

The approach is based on the well established practice of prolonging the life of objects by reducing the physical stresses on the object through well designed mounts for both storage and display. These mounts can be carefully shaped and padded internal supports, properly padded and tensioned boards for mounting or appropriately sized storage boxes with carefully arranged acid free tissue rolls and balls. The theory and practice is so fundamental to conservation practice it is introduced to textile conservation students at The Textile Conservation Centre (TCC) in their first semester of study.[73] Excellent examples of its use can be found scattered throughout conservation literature. A CCI publication, *Hanging Storage for Costumes* (1993) presents it as a way of protecting structurally sound costumes in storage. It is offered as a way of reducing the degradative affects in objects made partially of rubber (Nuttgens & Tinker 2000). It is the theory behind the precision cut wooden storage mount for *Pratt Chair No. 2*, a polyurethane chair produced by Gaetano Pesce in 1984 and now in the collection at the VDM (Figures 80 - 82). The chair was originally quite flexible and has become more so since its creation. It is now so flexible that it is no longer self-supporting. In order to keep the chair from folding in on itself, splitting and sticking together the exact surface of the chair was mapped with a precision machine. The map was then used to cut a mount which supports every undulation of the chair.[74] When it is clear that nothing else can, should or needs to be done to an object, providing proper support is generally suggested to retard the onset or reduce the affects of further degradation.

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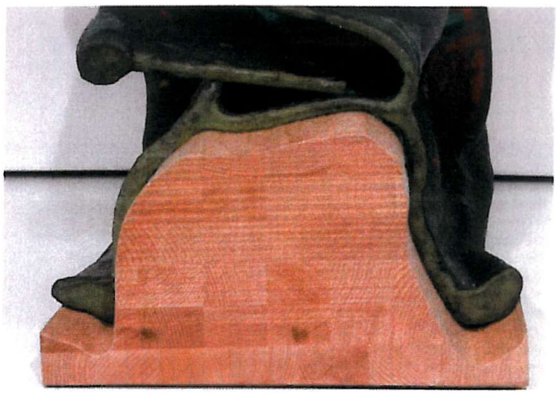
[73] Personal experience during the MA Textile Conservation programme, TCC, University of Southampton, 2001-2003.

[74] Personal conservations with Kathrin Kessler, Conservator, AXA Art Conservation Project in cooperation with the Vitra Design Museum, 4-6 April 2005

◄ **Figure 80: Four of nine *Pratt Chairs* designed by Gaetano Pesce c. 1984. *Pratt Chair No. 2* is located on the far left and is seen in its original condition. (Photo – Albus et al 2007: 68)**

▲ **Figure 81: *Pratt Chair No. 2,* designed by Gaetano Pesce c. 1984, in its currently degraded condition. VDM – no catalogue number (Photo – Albus et al 2007: 69)**



▲ **Figure 82: *Pratt Chair No. 2,* designed by Gaetano Pesce c. 1984, supported on a portion of its precision cut mount. VDM – no catalogue number (Photo – Albus et al 2007: 70)**

If applied to the *Globe* as described above it would reduce the stress on the fibres and yarns in the draping fabric. It would do the same for the foam and adhesive at any point where the fabric is still adhered. If constructed in a way that lifted the loose cushions just off the upholstered surface it would eliminate the stress they apply to the shell upholstery pads through slow compression. However, if constructed in a way that required it rest on the lower two pads of the shell upholstery it would risk adding stress to these pads through further compression.

What such a support for the *Globe* would be made of was not discussed with those who offered it as a suggestion. It would need to be very lightweight in order to limit the addition of new stresses in the chair from added weight. It would need to be relatively strong and rigid in order to not buckle under the weight of the fabric previously adhered to the upper three pads. Consideration would need to be given to whether or not its application sealed the polyurethane, polychloroprene, and wool from air exchange sufficient enough to reduce the build up of degradation products. If it did the build up of such products would be likely to further accelerate the degradation processes in the chair (van Oosten 2002).

Like the second justification for the do nothing approach (Section 3.1.1), this approach accepts the fragility of the foam beneath the top cover fabric and admits that conservation treatments of such materials are rather unpredictable and therefore rather risky. In so doing it avoids interfering with the materials in a way that can not be reversed or might alter the natural degradation processes taking place in the chair. It would re-establish much of the original profile of the chair but would add a new layer to it which might be just as visually distracting. If determined to be so, like the previous option, it becomes a solution for the *Globe* in storage but not for the *Globe* on display.

3.1.4 – Conserve the foam and adhesive in situ with re-adhesion or encasement

Option number four would involve the *in situ* conservation of the foam and adhesive used to upholster the shell of the *Globe*. It and the fifth approach introduce the option of physical intervention as a means to conservation and each one has two slight variations on a general theme. One variation of the *in situ* conservation approach would be the re-adhesion of the original fabric directly to the original foam. The second variation on this theme would be to leave the original foam in place, build an encasing structure around it and adhere or otherwise secure the original fabric to this new structure. In both cases the foam and the adhesive secured to it would be left in its current location. The top covers would have to be partially or completely removed in the early stages of conservation. However, the adhesive secured to them would remain so and the covers would be re-secured to the chair in a manner and orientation as identical to the original as possible.

Prior to a careful examination of the chair the first variation which would involve re-adhering the original fabric to the original foam seemed a bit more than preposterous. Gill (2001) describes the surfaces she found on foams she conserved in an Ernest Race *Heron* chair, c. 1955, in the collection at the Geffrye Museum, London (1/1993/1&2) as 'crumbling'. When speaking of a polyether polyurethane foam cushion used to upholster the chair *Locus Solus,* Vandenbrouck (2004: 40) describes a 'strong formation of dust due to degradation of the foam inside the upholstery'. Objects like those in Figures 83 & 84 which contain fragile and crumbling foam are representative of many other objects in private and public collections today. Foam in a similar condition would never be able to support re-adhered fabric for any length of time. In many cases it is even questionable if an initial bond between the fabric and degraded foam could be established.

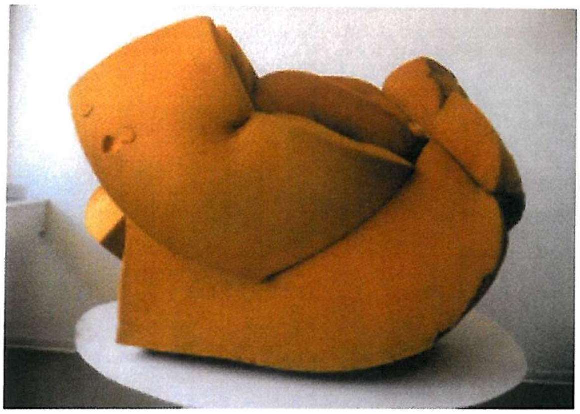
▲ Figure 83: A prototype for a chair by Charles Eames (date unknown) in which the foam is now severely degraded, crumbling. VDM – no catalogue number (Photo – J. Wickens)

▲ Figure 84: A detail of a prototype (c. 1959) for the *Cone* chair by Vernor Panton showing hard, brittle, deformed foam. VDM – MPA-1152 (Photo – J. Wickens)

However, as it has been described (Section 1.5.3), the foam in the *Globe* chair was not hard, brittle, crumbling or otherwise obviously degraded. In fact, it appeared that it just might be strong enough to support a re-adhered fabric. Lorne (1999) had successfully adhered adhesive coated open weave fabric to brittle, torn leaves during the conservation of *Still Life of Watermelons* (Figure 85), a polyether polyurethane foam sculptured carpet of watermelons and vines created by Piero Gilardi, c. 1967, and in the collection at the Museum Boijmans Van Beuingen, Rotterdam. During the conservation of *Pratone* (Figure 86), a 1 m x 1.5 m polyether polyurethane foam seat representing a stylized piece of lawn, created by Gruppo Strum, c. 1966-1970, and in the collection at the Museum Kunst Palast, Düsseldorf, it was shown that degraded foam could be re-adhered to itself and areas of loss in the foam could be filled by adhering crumbled foam to the object (Butzer 2002). Winkelmeyer (2002) also filled losses in the foam art object, *Funburn* (Figure 87). She however adhered shaped blocks of foam rather than the crumbled pieces utilized by Butzer. Each example illustrated that pieces could be re-adhered to polyether polyurethane foam of a similar age to that in the *Globe*. Admittedly, the pieces in these examples were much smaller and lighter than the fabric which would need to be re-adhered in the case of the *Globe*. This fact combined with the apparent fragility of the first 1 mm of the *Globe*'s foam surface (Section 1.6) suggested it might be necessary to stabilize and/or strengthen the foam surface in some way before attempting any re-adhesion of the fabric. However, there were plenty of examples which suggested that this would be possible as well. Grattan & Williams (1999) relate the story of *Prière de Toucher* a latex foam art object created by Marcel Duchamp in 1947 for the cover of the book *Le Surréalisme en 1947* which is currently in the collection at Chapin Library of Rare Books, Williams College, Williamstown, Massachusetts. Prior to conservation the foam was described as yellowed, hardened, embrittled and crumbled. It was conserved by consolidating the foam with Parylene C and Parylene N after which the degraded foam was described as greatly strengthened. During her conservation of an Ernest Race *Heron* chair, Gill (2001) was able to consolidate crumbling foam surfaces enough to hold them in position during the during the rest of the treatment of the chair. Lorne found that the edges of some of the leaves needing the treatment described above were too fragile to support it. However, by applying localized consolidation the fragile leaves were strengthened enough to support the repairs. Vandenbrouck (2004) found that through consolidation she was able to strengthen and stabilize the polyurethane seat cushion for *Locus Solus*, a necessary step before the top cover could be put back on the cushion. Thus, the condition of the foam in the *Globe* and the work of others offered the possibility that the chair's original top cover could be re-adhered to its original foam.

▲ Figure 85: *Still Life of Watermelons*, a polyether polyurethane foam sculptured carpet of watermelons and vines created by Piero Gilardi in 1967 – 154 x 306 x 25 cm. Museum Boijmans Van Beuningen, Rotterdam – no catalogue number (Photo – Hummelen & Sille 1999: 136)

▲ Figure 86: *Pratone*, a representation of blades of grass to be used as a piece of seat furniture, created by Gruppo Strum in 1966-1970. Museum Kunst Palast, Düsseldorf - no catalogue number (Photo – Greenberg 1999: 24)



▲ Figure 87: *Funburn*, a large twisted and tied foam sculpture, created by John Chamberlain in 1967. Museum für Moderne Kunst, Frankfurt/Main – no catalogue number (Photo – van Oosten et al 2002: Plate VIII)

Consideration would need to be given to whether or not the addition of a consolidant, if necessary, changed the fundamental nature of the foam so much that it was no longer worthy of preservation. Or was the addition of a non-reversible consolidant preferable because it offered a way to preserve something that if left untreated would not be here tomorrow? If a consolidant was applied would it slow the degradation of the foam? Or once again would it create a microenvironment in which air flow was inhibited causing the accumulation of degradation products and the acceleration of the degradation of the foam? How much of the original stitching and/or adhesive bonds in the chair would need to be released to gain access to the surfaces to be re-adhered would need to be considered. But if successful the approach offered a way to restore the original profile of the chair with a minimal introduction of new materials.

The second variation which would involve encasing the original foam offered a possible mechanism for the *in situ* conservation of foam and adhesive if the condition of the foam proved to make it unable to support the original fabric or re-adhesion directly to the foam proved to be less than ideal for other reasons. Once again, it would involve building a rigid structure around the foam as it sits in the chair and then re-securing the top cover fabric to that new rigid structure.

The idea evolved from an introduction to a technique that is known by many different terms: tackless, non-intrusive, non-damaging, minimally intrusive or non-interventive. No matter which term is used however the same primary process is being identified. A bare chair frame is presented with a desire to 're-upholster' it without causing further damage to the frame or the historical evidence it holds. In response, a base is built which is shaped to provide a foundation upon which the original profile of an upholstered piece can be re-established. This base can be attached to a chair frame in a way that causes little or no damage to the frame, the historic information it holds and any portions of original upholstery which might still be attached to it. Materials which re-build the desired profile and a new top cover fabric can be attached to the new base rather than the original frame. In so doing the frame is protected during the 're-upholstery' process with minimal damage being the result.[75]

By extracting from this technique the ideas that a form can be built to substitute for original upholstery material in a chair and such a form can be attached to a chair in a way that protects all historical evidence beneath it, the approach of encasing the fragile foam was conceived. The specific system imagined for the *Globe* would involve a modification of a variation on the technique described by Mascelli (n.d.) and Graves

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[75] This technique has been well described in dozens of publications including: Anderson 1988; Anderson 1990; Balfour et al 2001; Battram 1994; Calinescu & McLean 1995; Gill 1990b; Lahikainen 2001; Moyer et al 2003; The Society for the Preservation of New England Antiquities Conservation Center 1990; Twitchell 1990 & 1991; Van Horne 1991.

(1990) where a rigid, fibreglass structure is built to protect the frame of a piece of wooden seating furniture. Then new show fabric is attached to the structure rather than the fragile frame beneath. In the case of the *Globe* a rigid structure would be built around the fragile foam. In so doing the original profile of the chair would be captured and the foam could continue to degrade beneath it without affecting the newly re-established profile. The fabric could be adhered or perhaps otherwise attached to the new form providing it once again with full support.

Once again, the problem of possibly creating a microenvironment would have to be investigated as would the question of how much of the original stitching and/or adhesive bonds would need to be released. Whether a material could be found that would be thin enough to recreate the original profile without requiring compression of the foam beneath the new structure was not clear. How the new form would be attached to the existing structure of the chair would need to be determined or ideally a self-supporting structure would be designed which could simply rest in the chair shell beneath the fabric layer. Whether the potential solution would introduce the same problems that Graves (1990) describes, of the top cover and fibreglass structure changing shape at different rates due to changes in humidity, would need to be considered. It would involve the introduction of a rather significant foreign structure to the chair. But it might offer a way to restore the profile of the chair and retain the original foam in the chair without needing the foam to provide support for the top cover fabric as originally intended.

3.1.5 – Remove and replace the degrading materials

The final option considered regarding the conservation of the *Globe* was the possibility that removing and replacing the almost 40 year old foam and adhering or otherwise securing the original fabric to a new foam understructure was the most appropriate conservation option. As a piece of twentieth century art there is plenty of company for the *Globe* when considering this option. As an upholstered object there is plenty of precedent to help define the approach as valid.

There is an art work by Iain Baxter at the National Gallery of Canada, Ottawa titled *Animal Preserve No. 2* (no. 40101.1-503). It was created in 1999 and consists of hundreds of jars which have been filled with stuffed animals[76] and distilled water. In 2004 the animals were showing signs of deterioration and the conservation staff at the museum was beginning to consider whether or not it would be ethical to remove the water and replace it with something which would have more of a preservative effect on the animals. At the same museum there is a piece titled *Trans-Am Apocalypse No. 2* (no. 37493), created by John Scott in 1993. It is a car which has had the entire book of Revelations scraped into the paint on its surface. When it entered the museum's collection it retained its engine and all the fluids necessary for operation but both have subsequently been removed with the justification for the removal being the sacrifice of a lesser part for the preservation of what was most significant.[77] At White Cube, a contemporary art space in London's East End, *My Bed*, a work composed of more than 60 items including a bed, linen, a condom, underwear and bottles, created by Tracey Emin in 1998 has not reached a point where the condition of objects suggests they need to be replaced. However, the possibility has already been considered as an approach to future care (Hale 2004). During the conservation of *Mare*, a polyether polyurethane foam sculpture of the sea, created by Piero Gilardi in 1966, the option of removing a seagull due to its state of degradation did not need to be considered because it was already gone. What needed to be considered was whether or not to create a new one to replace it (Rava et al 2004). In each case the removal and/or replacement of part of the art object was or is being considered in order to preserve an original outward appearance, the exact issue which would have to be considered if the original foam in the *Globe* were to be removed.

Within the upholstery conservation profession the approach has already been taken during the conservation of the seat and back cushions displayed in an office designed for Edgar Kaufmann by Frank Lloyd Wright between 1935 and 1937. The office entered the collection of the V & A in 1974. It was installed in the museum for a short period in 1989 and then two-thirds of it was shipped to Japan for an exhibition in 1990. In preparing for the shipment the padding in all of the cushions was identified as being too

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[76] The equivalent English term is soft toys.

[77] Both of these examples were presented by Richard Gagnier, conservator at the National Gallery of Canada, during the Canadian Association for Conservation Workshop, 26-27 May 2004, *Unusual Materials, Unconventional Treatments*.

fragile to travel and as a result new pads for all of the seats were crafted (Wilk 1993; Wilson 1999). In March 2004 the VDM had a master upholsterer working in the museum removing degraded foam from many of its artefacts and replacing it with new. The original top covers were conserved and reused but the original foam was discarded.[78] At the Old York Historical Society, York, Maine, chairs upholstered with foam rubber(?) in the mid twentieth century had degraded to a point that the foam was 'spilling out onto the floor'. Once again, the foam was removed and replaced with new foam rubber(?) and the original top covers were reused.[79] At the London Transport Museum, in 1980, a 1956 *Routemaster Bus* had its degraded foam rubber(?) seat cushions removed and replaced with new foam rubber(?). In this particular case, the replacement foam has now degraded and it needs to be replaced again. This time, a different synthetic foam will be used.[80] At the Museum of Modern Art (MoMA), New York, the original foam in the seat of an Eero Saarinen *Tulip* chair (c. 1955-1956), which was permanently deformed when a patron inadvertently sat on it, will be removed. The foam will then be replaced with a material which will allow the original profile of the cushion to be rebuilt and the original top cover will be retained and reused.[81]

As stated, this approach has two slightly different variations. The first would be to replace the discarded foam with currently produced polyether polyurethane foam. Such foam would not be an exact replica of that used in 1968 as formulations have changed in the intervening 40 years since the *Globe* was originally upholstered. It would however offer the possibility of introducing a new material with a look, feel and chemical composition very close to the original material. Such an introduction would be likely to satisfy those who argue that an upholstered object needs to be conserved using construction materials and methods very similar to those used during its original production in order to truly present a profile reflective of the original.[82] However,

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[78] Email communications with Kathrin Kessler, Conservator, AXA Art Conservation Project in cooperation with the Vitra Design Museum, 18 March – 26 July 2004

[79] Personal conversation with Tom Johnson, Curator of Collections, Old York Historical Society, 26 February 2004

[80] Personal conversation with Bob Bird, Senior Curator of 3D Collections, London Transport Museum, 9 March 2004

[81] Personal conversation with Roger Griffith, Associate Sculpture Conservator, MoMA, 17 March 2004

[82] An opinion expressed by various participants during *French and American Collaboration on Upholstery*, a workshop held at the Museum of Fine Arts, Boston, Massachusetts and Marble House, Newport, Rhode Island, 24-25 October 2003 and co-sponsored by the American Institute for

whether such an introduction crossed the ever moving line between conservation and restoration would also need to be considered. If selected as the approach to take Bert Ufermann offered that the current upholster of *Ball* chairs could supply a new set of pads for the *Globe*. Or perhaps it would be possible to obtain a set of pads from the upholsterer who reupholsters *Ball* chairs for Michael Marks.

The second variation on this remove and replace option would be to remove the original foam and replace it with a conservation grade foam known to be more stable and long-lasting[83] than polyether polyurethane foams. The foams commonly used for this purpose when applying the minimally intrusive technique described in Section 3.1.4 are the polyethylene foams Ethafoam® and Plastazote®. The primary advantages of the use of such foams is that they degrade at a much slower rate than other foams and do not release degradation products likely to harm museum objects. The primary arguments for not using such replacement foams are that they are not reflective of what would have originally been used in the object being conserved and their use produces a profile of a different character than that which would have originally existed.

In either of the remove and replace options how the fabric would be re-secured to the newly shaped understructure would need to be considered. If new polyurethane upholstery foam was used could a twenty-first century upholstery adhesive be used as well? Each option offers the promise of a restored profile but how much information and object integrity would be lost in the process of applying it?

Conservation of Historic & Artistic Works, the Museum of Fine Arts, Boston and the Preservation Society of Newport County, Rhode Island

[83] This generally accepted fact was questioned by Mark Anderson, Upholstered Furniture Conservator and Adjunct Assistant Professor, Winterthur Museum & Country Estate and University of Delaware during *French and American Collaboration on Upholstery*, a workshop held at the Museum of Fine Arts, Boston, Massachusetts and Marble House, Newport, Rhode Island, 24-25 October 2003 and co-sponsored by the American Institute for Conservation of Historic & Artistic Works, the Museum of Fine Arts, Boston and the Preservation Society of Newport County, Rhode Island. He had personal experience with upholstery conservation treatments in which the Ethafoam® introduced in the conservation process became quite fragile in the space of about 10 years. This has not been a common occurrence and it was suggested it was probably the result of a bad batch of foam but in any case it is a concern worthy of consideration.

3.1.6 – Conclusion

The five options described above are far from mutually exclusive. The first three present primarily options for storage which could be used separately or in combination. The *Globe* could be left on display until it was no longer considered appropriate for such purposes. Then it could be moved to a storage facility and encased in a degradation slowing environment. Or, one of the foam pads could be removed from the chair and placed in degradation slowing storage. A new pad could take its place in the *Globe* and then the remaining four pads could be conserved *in situ* or removed and replaced as well. Or, the lower two pads could be conserved using the re-adhesion method taking advantage of the fact that these pads would be put under very little physical stress by the method. A support could be built to support the loose cushions just off the surface of these pads. Then the upper three pads could be encased or removed and replaced.

Each of these conservation approaches and any combination of them, with the exception of the option that involves doing absolutely nothing, would require significant investigation before it could be put to use in the conservation of the *Globe*. Each option would conserve slightly different aspects of the chair in slightly or radically different ways. Some would involve no intervention others would require significant alterations to the structure of the chair. Which option offered the best way forward for the *Globe*?

3.2– The significance of the *Globe* and its materials

To this point the *Globe* and the greater class of *Ball* chairs to which it belongs have been described in great detail. What the chair and particularly the upholstered portions of it are constructed with has been presented at different levels. How the chair has degraded since its original date of manufacture and likely reasons for these changes have been outlined. Possible ways of approaching the conservation of the chair have been offered. Why the materials in the *Globe* are worth conserving and what specific attributes of the chair might take priority in a conservation process may not yet be obvious.

There is of course the basic question of whether the *Globe* is significant from an art historical perspective, a social history perspective or any other perspective that might make it worthy of museum space. However, like the point that preserving memories of the human journey is a worthwhile pursuit had to be accepted without qualification at the start of this work, the point that the *Globe* is worthy of museum space must be accepted now. It has been collected by the V & A. Other *Ball* chairs have been collected by museums around the world. The individuals, committees or other parties responsible for their acquisition decided they were worthy of museum space. That is fine, acceptable and will not be contradicted. However, since its acquisition the *Globe* has degraded and what should be done about that degradation needs to be considered. Which parts or characteristics of the chair hold memories which ought to be preserved or are future historic evidence worthy of conservation? Upholstery foams, adhesives and wool fabrics are all around us. They are still being manufactured. They are still being used in the upholstery process. Does this not make the materials in the *Globe* far from precious? If the materials themselves are not precious then certainly would it not be most simple to remove and replace the materials in order to restore the shape of the chair? If this was done then maybe new wool fabric could be adhered to new polyether polyurethane foam using a new polychloroprene adhesive. Such an approach would not only restore the shape of the chair but it would re-upholster the chair much as it would have been done originally preserving part of the method of construction and the shape of the chair. But if such an approach was identified as ideal then why not simply buy a new chair to replace an old degrading one? After all *Ball* chairs themselves are still being produced. Is there something or more than one thing that makes the physical object of the *Globe* and the materials used in its production worthy of conservation?

3.2.1 – Original materials

First and foremost, the materials in the *Globe* are original. 40 years ago this fact would probably have been insignificant to the upholstery history and conservation profession and the chair would have been subjected to the then common practice for museums to send upholstered pieces to commercial upholsterers. These tradespeople would remove all existing materials from the frame and then reupholster the pieces with new fillings and fabrics (Adler 1988; Anderson 1988 & 1990; Fairbanks & Nylander 1987; Fikioris 1990; Gill 2004; Rivers & Umney 2003). In part this full re-upholstery took place because commercial upholsterers were required, by law, to remove all old material and replace it with new (Anderson 1990; Fairbanks & Nylander 1987). Additionally, with rare exceptions, conservators and all others in the museum world were simply not concerned with preserving all aspects of upholstered objects (Anderson 1990). And, it will be shown that the practice of restoration was so intimately linked to the practice of upholstery that it was not until a significant shift in thinking began to take place that curators and conservators began to be concerned with conserving upholstered pieces rather than primarily restoring them to objects which looked like new.

The fact that upholstered furniture has always been linked to the tradition of restoration is perhaps initially clear thanks to first hand experience. Whether the upholstered chair or sofa is a personal possession, that of a neighbour or a piece included in the latest home makeover television programme or publication, people are familiar with the idea of taking a damaged or even perhaps perfectly sound piece of furniture and having it repaired and recovered to match a new decorative scheme. In some cases the process might involve stripping the furniture frame of all of its old upholstery material before applying new. In other cases it might simply involve a new slip cover made to hide the old. Admittedly, the process described might not fit the strictest definition of restoration, 'to bring back to an original condition'[84] for the new cover might be of a

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[84] As defined in The American Heritage Dictionary of the English Language. 2000. (Fourth Edition). Boston: Houghton Mifflin Company.

new pattern, the new upholstery material might be of a different quality or the use of a slipcover might not reflect the way a piece was originally covered. But in any case, the idea of taking a piece of upholstered furniture and making it look new again is not unfamiliar to most inhabitants of the western world.

This idea and practice is not however simply a modern day phenomenon. In fact, one might guess that thanks to mass production and inexpensive furniture suppliers like Ikea and Argos the practice is less common today than in the past. Perhaps the best evidence for the long-term existence of the practice of re-upholstery is the fact that very few upholstered objects in museums and auction houses today retain upholstery materials which are contemporary to their frames. However, additional evidence can be found in relevant literature. Some of the references are offered in generalities. Jobe (1987) declares that due to the perishable nature of textiles and ever-changing fashion most of American seating furniture and almost all beds have been reupholstered. Swain (1990) points to the time when it was common practice for repairmen to travel door to door offering the service of rush seating repair. Other historians point to specific archival evidence. Bonnet and Jamet (2003) record that a French upholsterer of the 1780s noted in his account books that he had de-upholstered some of his previous work for a customer in order to add a layer of feathers to the seat cushions. Hayward (2001) comments that the Great Wardrobe accounts of King Henry VIII suggest that William Green, the King's coffer-maker, refurbished and recovered existing chairs in the King's inventory. With this evidence and more it is easy to see that restoring upholstered furniture is a practice that has endured for centuries and with some effort might even be able to be traced back to the late fifteenth century when it has been suggested upholstery was first recognized as an independent trade (Trent 1990).

With such a strong and lengthy link to the practice of restoration it should really come as no surprise that upholstered pieces in the care of museums were reupholstered as a matter of course. This reality becomes even more understandable when the development of general museum practice is also considered. Ward (1986) states that for a century prior to 1930 museums employed restorers and the concept of a museum conservator did not exist. He goes on to say that in 1930 the term conservation began to find its way into the museum vocabulary and this change combined with the first conference on using scientific methods to examine works of art marked the beginning of an evolution.

In his opinion, this evolution drew significantly from the ancient craft of restoration, became informed by the results of materials research and resulted in the development of modern conservation. Viñas (2005: 81) does not place his discussion of the development of conservation quite so firmly in the realm of museum practice. However, unequivocally, he states that 'Pure restoration, thus preceded conservation: out of the craft of restoration came conservation.'

So restoration gave birth to conservation. Restoration was a long established practice in museums. It was a long established and is a still practiced approach in the upholstery trade. What was the previously mentioned shift in thinking that moved the care of upholstered furniture in museums out of the realm of pure restoration? What was the shift that now marks the materials in the *Globe* as worthy of preservation rather than replacement? Thornton (2001) points to the 1979 Conference on Historic Upholstery and Drapery held at the Museum of Fine Arts, Boston as the major international turning point. Other authors writing prior to Thornton identify this same conference as having a significant influence on upholstery conservation (Anderson 1990; Trent 1990). By examining a publication which grew out of this conference, but was not released until 1987 (Cooke), it becomes clear that the shift in thinking that is being identified is characterized by a shift to an acceptance that there is more value in an upholstered piece of furniture than its outward appearance. Historic pieces of furniture hold historic evidence with regard to historic upholstery techniques. They hold evidence regarding fabrics and fillings used, techniques employed to secure these materials and the profiles which resulted from the efforts. This information, combined with archival research greatly expands the knowledge of upholstery history and preserving this knowledge is not only worthwhile but does much to make it possible to more accurately interpret historic furniture.

In the almost 30 years since this conference the practice of upholstery conservation has matured in many ways. In so doing the importance and supremacy of original material in an upholstered object has become widely accepted. A case study which clearly demonstrates the evolution to this acceptance is nicely presented by Gentle (1984 & 1990). In 1980 the conservation of a set of seventeenth century brocaded slip covers original to the *Dolphin Chairs* of Ham House, a seventeenth century house in Richmond-upon-Thames, was begun. At this time the approach was to give each cover as full a conservation treatment as possible, which often meant that original stitching and construction information was disassembled and perhaps removed. Part way into the project work stopped for almost four years and when the work was picked up again a shift in thinking had taken place. Now people saw that there was significant value in original stitching and construction. In order to accommodate this new understanding the conservation approach for the chairs was altered and elements of original stitching and construction were released only if the same element was left intact on another piece and if there was no way to proceed with conservation without doing so.

This evolution in thinking has been the driving force behind others' efforts to develop new conservation techniques. Some have experimented with *in situ* cleaning methods and new infill methods in an effort to find ways to preserve all of the original materials and construction elements on a chair but at the same time provide an acceptable aesthetic presentation from the curatorial perspective (Chewning & Mailand 1993). Battram (1994) recounts the conservation of an *American Easy Chair*, c. 1780, which retained its original padding, linen undercover and deck. This material was covered with a transparent fabric and then supplementary fabric and padding was stitched to this new material. And in yet another case study, when original stitches of an Ernest Race *Heron* chair and footstool had to be cut to allow access for conservation the threads were left in place as evidence for the future. Degraded foam which was no longer able to serve its functions as a material that shaped the profile of the chair and supported top cover fabric and user was encased in Melinex™, polyester film, envelopes. These envelopes were left in the chair, again as evidence of the original materials used in its construction (Gill 2001).

There are numerous other treatments where part of the primary goal of conservation was to retain original elements and over time these treatments and the value of these elements has become so accepted that in the most recently published definition of upholstery conservation the protection of original elements has been included as one of the main aims of upholstery conservation (Gill 2004). In 1990, Lahikainen commented that during conservation projects it had become paramount that when a piece of original upholstery was found its preservation *in situ* took place. This was due to the fact that an evolution in thinking had redefined such pieces as evidence of a historic practice that was only beginning to be understood. Such thinking is still valid today.

But is it reasonable to apply the importance of original material to a 40 year old object like the *Globe*? Can an argument that original materials need to be conserved at almost any cost in order to preserve evidence of historic practices really be applied to an object that did not exist when many people alive today were born into this world? Efforts at The Colonial Williamsburg Foundation show that some members of the historic preservation profession think so. In this collection there are seventeenth century pieces which have been re-upholstered using jute webbing. This material degrades quite quickly and often when conserving such pieces the decision is made to remove the webbing and replace it. This process is acceptable within the conservation approach adopted by museum staff as it readily accepts the removal of later additions to furniture. However there are pieces of twentieth century furniture in the collection as well and many of these pieces were originally upholstered with jute webbing. In these pieces the museum is faced with a challenge to retain and stabilize the rapidly degrading original material. The same approach that allows the removal of later additions requires the retention of all original materials at all cost.[85]

It is more than possible that others would strongly disagree and argue that materials with such a short history are not worthy of such preservation efforts. However, it has been roughly estimated that less than 10% of upholstered furniture in museums today retains its original upholstery (Rivers & Umney 2003). The *Globe* is one of these pieces. If its original materials are removed museum professionals will be contributing to the loss of a rare commodity rather than working to preserve it. They will be refusing to learn from the past. They will once again be removing materials which seem insignificant to them but may be very significant to others some number of years to come. In order to keep history from repeating itself the original materials in the *Globe* need to be preserved if that is possible.

3.2.2 – Original design and production process

From 12 August to 31 October 2004, the work of five internationally known furniture designers (two individuals and three two-member partnerships) was exhibited at the

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[85] Personal conversation with Tara Gleason Chicirda, Associate Curator of Furniture, The Colonial Williamsburg Foundation, 16 April 2004

Crafts Council Gallery, London. These eight artists had been short-listed for the tenth annual Jerwood Applied Arts Prize and the exhibition presented the work they had submitted for consideration. Part of the exhibition included audio recordings of interviews of each artist or artist pair carried out by Jo Saunders, Education Manager at the Crafts Council.[86] In response to two questions, 'How would you describe your design and production process, from concept, through materials and technologies to the end product?' and 'What are your hopes for the future of furniture design?' several answers were given which suggest that if the heritage preservation profession wants to fully conserve twentieth (and twenty-first) century furniture, of which upholstered artefacts are a subcategory, it is not only the original materials that need to be conserved. Those comments were (bold italics added by the author for emphasis):

> **In the words of Tom Dixon –**
> I think furniture has become a bit static of late and I'd hope to see the excitement that must have been in the Fifties or the Sixties come back again. ***That depends a lot on an evolution in people's living habits or an evolution in materials technology or manufacturing technology*** so with any luck those new processes will arrive and people will start wanting to live in different ways and we'll be able to design to suit.

> **In the words of El Ultimo Grito (Roberto Feo and Rosario Hurtado) –**
> RH: It depends on the piece because ***some projects start from a certain material*** or an idea that you have, and other ones come from a brief so it is quite a different approach, so it's not really like one set way of working.
> RF: At the end, ***what is important for us is that the end product conveys the ideas that trigger the project either by the material*** or by the concept or by the brief!
> ...
> RF: This is a difficult question because furniture is an area of work where it's quite challenging to try to generate new proposals because furniture is related to culture and as long as culture doesn't change it's very difficult to change furniture as well. So the only thing that you end up doing is transforming the shape and ***it becomes more an exploration of materials***.

> **In the words of BarberOsgerby (Edward Barber and Jay Osgerby) –**
> JO: At the model making stage ***we really start to focus in on the type of materials we'd like to use*** for a product. Obviously we've had something in mind but generally as the process evolves we sort of restrict that choice and start thinking about material in a more specific way.

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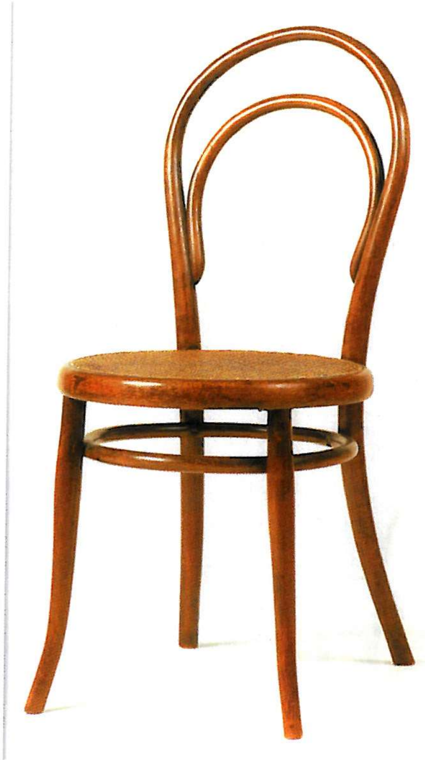
[86] A transcript of the interviews was and may still be available from the Crafts Council and handwritten portions of the interviews were transcribed by and are available from the author.

> EB: On other projects ***you can start with a specific material and design using the constraints of the material.***
> JO: Generally there are two ways in which we work with manufacturers, the first is that the manufacturer will approach us and that happens fairly often where they have evolved a brief themselves and are looking for someone to design a new product or a new range for them. The second way we work is that we'll evolve a project or brief ourselves which we feel is appropriate for a specific manufacturer maybe because ***they have a specific manufacturing process we want to explore*** or they have a particular way of working that we are interested in.

These words indicate that, at least for these twentieth and twenty-first century designers, the design process is not separated from the choice of materials or the manufacturing process. Sometimes it is the materials or the process that provide the inspiration for the eventual design. At other times it appears that it is the design that inspires the choice of materials or manufacturing process. But in any case, design, manufacturing process and materials are not distinct. If the furniture of these designers ever needed to be conserved a thorough conservation effort would need to encompass the materials involved in its creation but also any evidence which might provide details of the design and manufacturing processes that produced it.

The links between design, production and materials which show that they are not distinct elements in the furniture trade are much more far reaching than the Jerwood Applied Arts Prize short-list. They can be taken back to 1856 and the creation of Michael Thonet's process for steaming and bending rods of beech wood (Drexler 1973). The introduction of this process made a whole new range of furniture available (Figure 88). Sparke (1986) comments that between World War I and World War II the general opinion that it was inappropriate to use modern machines to perpetuate old furniture styles seemed to proliferate. This opinion combined with pioneering designs and new materials led to a rejection of the previously popular period revival furniture. Machines of production, designs and materials worked with each other to produce new furniture and a desire for it. Members of the Bauhaus movement reinforce the link between the three elements with their efforts to develop new techniques and materials which would make it possible to produce their designs with high-quality machine processes (Stimpson 1987).



◄ Figure 88: ***Chair No. 14*****, an 1859 creation of Michael Thonet which owes its existence to the adaptation of a process for steaming and bending wood. (Photo - Von Vegesack et al 1996: 25)**

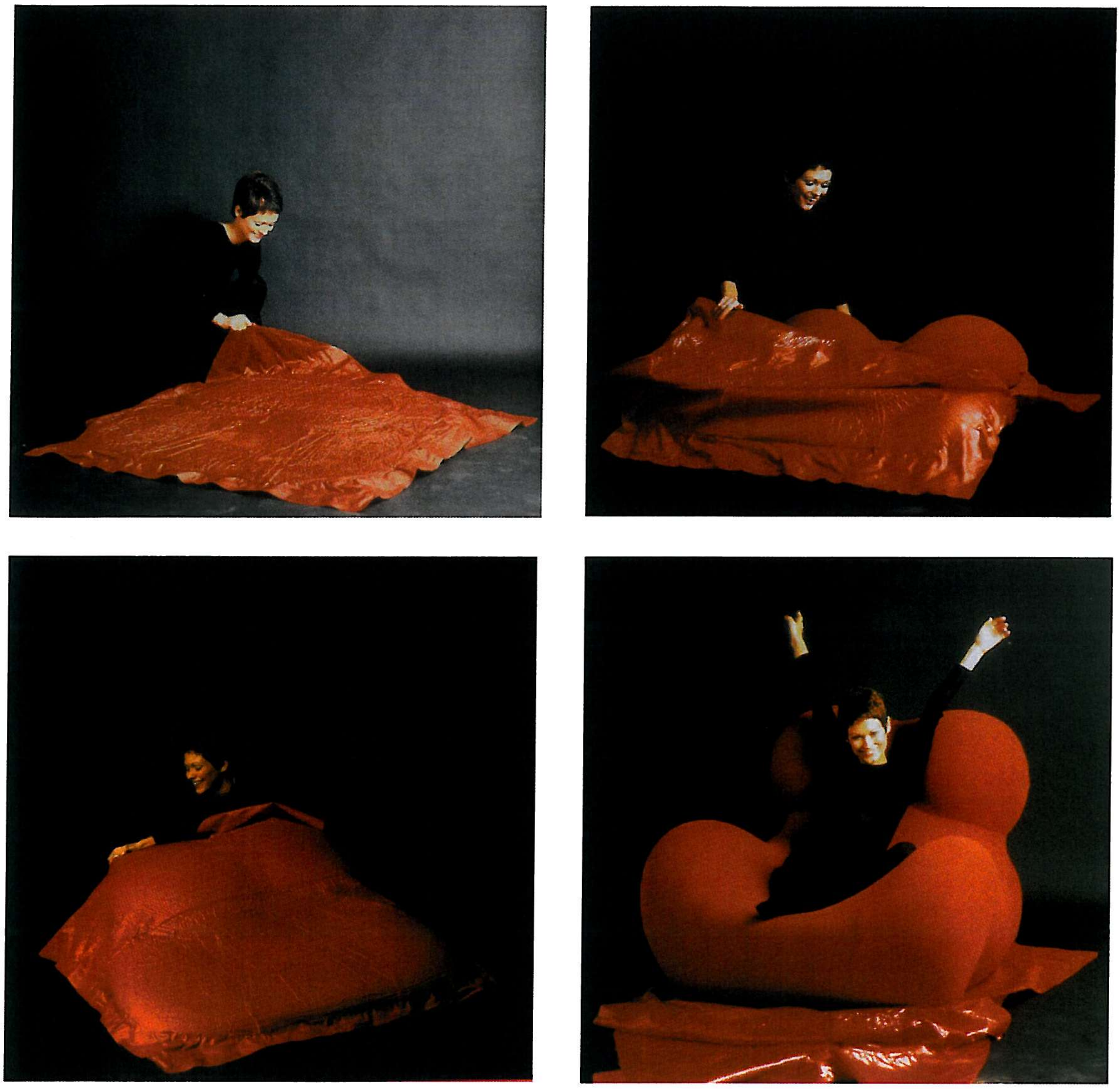
In the work of individual designers there are many other links. Marcel Breuer's use of tubular steel to find another way to fashion legs for a chair (Figure 89) is highlighted by Nelson (1953: 18) when arguing that the 'mainspring of progress in the technique of manufacturing furniture lies in bringing new materials into the field.' Charles Eames adapted the process of cycle welding, developed by Chrysler, to fix metal legs to plywood seats. Eames and Harry Bertoia (Figure 90) used wire to create 'see-through' chairs which fit nicely into new, open plan interiors (Rivers & Umney 2003). Ernest Race Limited became known for incorporating 'non-traditional materials' into new furniture designs (Gill 2001).

▲ Figure 89: Marcel Breuer's *Model No. B33,* (1927-28), which used tubular steel to fashion a new method of chair leg construction. (Photo – Fiell & Fiell 2002: 34)

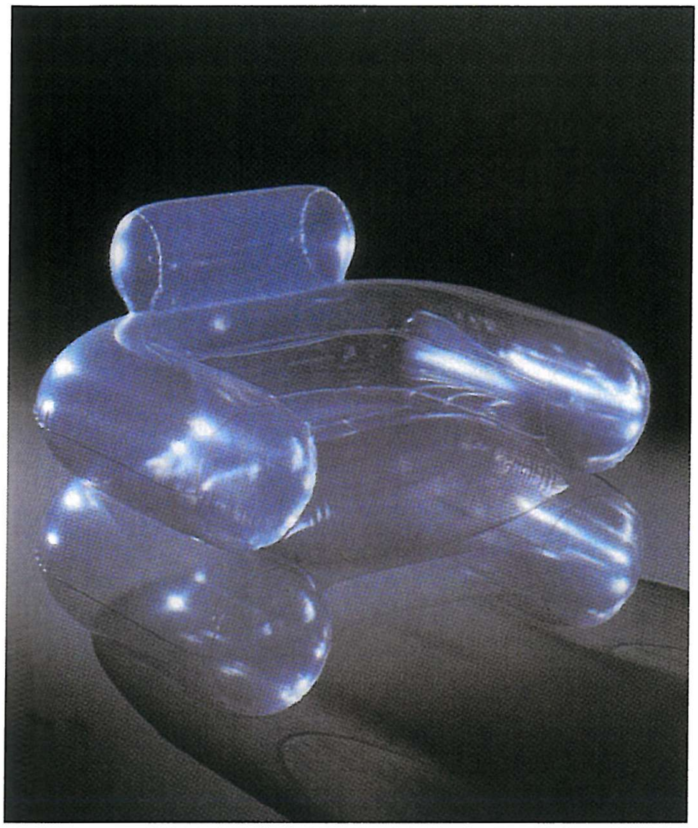
▲ Figure 90: Harry Bertoia's *Diamond* chair (1952), a see-through chair for a see-through home interior. (Photo – Fiell & Fiell 2002: 30)

Thus the link between design, materials and method of production exists today. It has been shown to have existed in the first half of the twentieth century and even earlier but does it exist for the *Globe*? Is the link important for this chair and thus is the method used to create it something that needs to be considered in its conservation?

It certainly exists for plastics in general. Williams (1996) comments that with the introduction of plastics designers were set free to create novel shapes, in fact almost any shape, in any colour that inspired. Watson (2002) seconds this drawing a direct link to household products and particularly furniture. Greenberg (1999: 12) remarks that the new array of synthetic materials made it possible for designers to create furnishings that were 'outrageous and never-before- tried'. Gaetano Pesce took advantage of the fact that polyurethane foam could be moulded and compressed to develop the *Up Series* in 1969 (Figure 91). The result was furniture which could be produced without high tooling costs and packaged so that it could be carried home under the arm of the latest consumer (Fiell & Fiell 1997; von Vegesack et al 1996). In 1967, Gionatan De Pas, Donato D'Urbino, Paolo Lomazzi and Carla Scolari used the process of welding polyvinylchloride sheeting with radio-frequencies to produce an inflatable chair, *Blow* (Figure 92) (Fiell & Fiell 2002).



▲ Figure 91: Gaetano Pesce's *Up5* (1969) which could transform from flat compressed foam to comfortable resting place in about an hour. (Photos – Greenberg 1999: 180-181)



◄ Figure 92: *Blow*, by Gionatan De Pas, Donato D'Urbino, Paolo Lomazzi and Carla Scolari, c. 1967, a chair created of only plastic and air thanks to the process of welding with radio-frequencies. (Photo – Fiell & Fiell 2002: 55)

Korvenmaa (2003) draws the link to specifically Finnish plastic furniture in a comment that plastic technology completely liberated the form a piece of furniture needed to take. For others, Aarnio himself has been seen to be preoccupied with new materials, new methods, the process of production, technical solutions and rounded forms drawing the argument to the specific person of Aarnio (Eidelberg 1991; Englund & Schmidt 2003; Hai 2003; Kalha 2003). And finally the link between the important connections between design, materials and production processes and Aarnio's *Globe* chair are established by Aarnio himself. When discussing his work he explains that the focus on rounded forms was established because it was the easiest form to execute through industrial production and when specifically discussing the *Ball* he explains that the design was based simply and solely on the spirit and language of the material (Adelta n.d.; Barbosa & Guimarães 2001).

Sparke (1986) suggests that an account of modern domestic furniture that does not balance the way it has been used with the story of its production is incomplete. The development of materials has been said to have been almost completely chronicled in the story of the chair (Greenberg 1984). Nelson (1953) claimed that every design innovation, new material and technical invention found its most important expression in the chair. It is clear, the story of twentieth century furniture design can not be separated from the materials and processes used to create the designs. This is also true for the specific piece of twentieth century furniture embodied in the *Globe*. The elements of design, materials and process are intimately linked in twentieth century furniture and they should not be separated in the process of conserving it.

Some relatively recent upholstery conservation projects are examples of work that has sought to conserve upholstery methods alongside other aspects of the pieces in question. The *Denon Chairs*, an early nineteenth-century pair of French chairs in an Egyptian Revival style designed by Baron Dominique Vivant Denon (1747-1825) were conserved for the V & A (W.6-1996) and the National Museums and Galleries on Merseyside (WAG-1996.64) using a system that attached traditional upholstery to a non-damaging frame. The solution used new materials which were foreign to the original design of the chairs to protect the frames. But it then used materials and techniques to reshape the profiles of the chairs which were understood to be very similar to what would have originally been used on the frames (Balfour et al 2001). A suite of gilded and silk upholstered French furniture, now known as the *Swan Collection*, dating to the late 1700s and probably originally made for Marc-Antoine Thierry de Ville d'Avary (1732-92), the Commissaire-Général of the Garde-Meuble de la Couronne was conserved for the Museum of Fine Arts, Boston. The project used the same basic approach of re-upholstering the pieces with traditional methods but attaching the upholstery to the frame of the chair using non-intrusive techniques. It this case fewer 'foreign' materials were used and therefore perhaps a fuller reflection of traditional techniques was achieved (Moyer et al 2003).[87] A similar example was recently described by Nancy Britton, upholstery conservator at the Metropolitan Museum of Art, New York when explaining the approach taken during the conservation of a klismos chair from the early 1800s.[88] As these examples all relate to upholstery methods of earlier centuries they do

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[87] Information presented at *French and American Collaboration on Upholstery*, a workshop held at the Museum of Fine Arts, Boston, Massachusetts and Marble House, Newport, Rhode Island, 24-25 October 2003 and co-sponsored by the American Institute for Conservation of Historic & Artistic Works, the Museum of Fine Arts, Boston and the Preservation Society of Newport County, Rhode Island

[88] Information recorded by the author at *Upholstery +*, an interim conference organized by the ICOM-Poland Committee and the ICOM-Conservation Committee Leather Working Group, Textile Working Group, and the Wood, Furniture and Lacquer Working Group in concert with the National Museum in Cracow, Jagiellonian University, Cracow, Poland, 13-18 May 2007 during the presentation Four upholstered chairs: four solutions.

not offer specific techniques which might help conserve the links between design, materials and production processes in twentieth century foam upholstered objects but they do set a precedent for working to do so.

3.2.3 – Original design

At the beginning of this section the fact was presented that 30 to 40 years ago museum professionals were primarily only concerned with preserving, at some level, the outward appearance of a chair and that in the years since then the preservation of materials as well as appearance has become just as important. The ensuing argument has made it clear that for the *Globe*, the preservation of original upholstery materials and the design and production process used in the original construction of the chair are paramount if the chair as a whole is to be conserved. It needs to be clear however that the outward appearance of the object is still significant. Conservation of materials and the process of design and production without consideration being given to the original profile of the chair and whether it needs to be reconstructed would not be appropriate.

It is well established in the upholstery conservation profession that the original profile of a chair is important and worthy of preservation. The techniques of non-intrusive upholstery were developed and continue to be perfected in order to allow profiles to be restored to a chair within the limits of what conservation ethics require for the rest of the object. Gill and Eastop (1997) present details of the conservation of a pair of c. 1730 side chairs, possibly designed by William Kent, for Chiswick House, the oldest Palladian style house in England. Lahikainen (2001) details two projects. The first involves a mid-eighteenth century French chair attributed to Jean Baptist Tilliard I maintained in the collection at the Detroit Institute of Arts (Acc. no. 60.89) and the second a chair of the same era, also French but attributed to Nicolas Heurtaut and maintained in the collections at the Cleveland Museum of Arts (Acc. no. 1989.160). Each one of these case studies involves the use of new, conservation grade materials to restore the original profile of an object and is an excellent example of the careful research and meticulous techniques used to recreate such profiles with historical accuracy when little evidence remains on the object. Recently completed projects within the context of historic houses can be viewed at Osborne House, Queen Victoria's home on the Isle of Wight[89], The Royal Palace of Stockholm, the official residence of the king of Sweden[90] and Marble House, the late nineteenth century Newport Rhode Island summer home of Mr. and Mrs. William K. Vanderbilt[91]. The British Galleries at the V & A[92], galleries at the Peabody Essex Museum, Salem, Massachusetts[93], the Museum of Fine Arts, Boston[94], the Metropolitan Museum of Art, New York[95] and many, many, others present examples of upholstered objects with conserved profiles. This historical and current practice is probably reason enough to consider the restoration of the profile of the *Globe* an important part of its conservation. It is evidence that those involved in making the decisions about what is significant about a piece of upholstered furniture have and still do think that the shape of the chair matters.

However, if it is appropriate to question past and current practice and ask if the shape of a twentieth century chair, and that of the *Globe* specifically, is important there are at least three reasons to think it is. First, at the start of the twentieth century chairs were very much comfortable sitting objects. They were well padded, often sprung and designed with the physical needs of the user in mind. Throughout the century the chair slowly evolved becoming in many ways a piece of sculpture (Sparke 1986). This definition may be tenuous with an object like *Polyprop*, (1962-1963) by Robin Day, which is clearly a chair (Figure 93). However, it is more than hinted at in a photo of four chairs and a coffee table from George Nelson's 1963 *Catenary Group* for Herman Miller as they sit in one of the large public spaces in the Detroit Institute of Arts (Figure 94). The same could be said of Nelson's (1953) comparison of the wire constructions of Calder and the wire chair frames designed by Charles Eames. In objects like *Pratone* (Figure 86, Page 95) and Gaetano Pesce's *Up 7* (1969), a 'chair' in the shape of a foot (Figure 95), no imagination is needed to come to a willingness to define chairs as sculptures. Greenberg (1999: 138) even goes as far as describing Aarnio's chairs as 'the work of a sculptor whose medium happens to be plastic'. This opinion that chairs are

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[89] Personal visit July 2002 and personal conversation with Michael Hunter, Curator, Osborne House, English Heritage

[90] Personal visit May 2005

[91] Personal visit during *French and American Collaboration on Upholstery*, a workshop held at the Museum of Fine Arts, Boston, Massachusetts and Marble House, Newport, Rhode Island, 24-25 October 2003 and co-sponsored by the American Institute for Conservation of Historic & Artistic Works, the Museum of Fine Arts, Boston and the Preservation Society of Newport County, Rhode Island

[92] Personal visits 2001-2007

[93] Personal visit October 2003

[94] Personal visit October 2003

[95] Personal visits 1997-2000

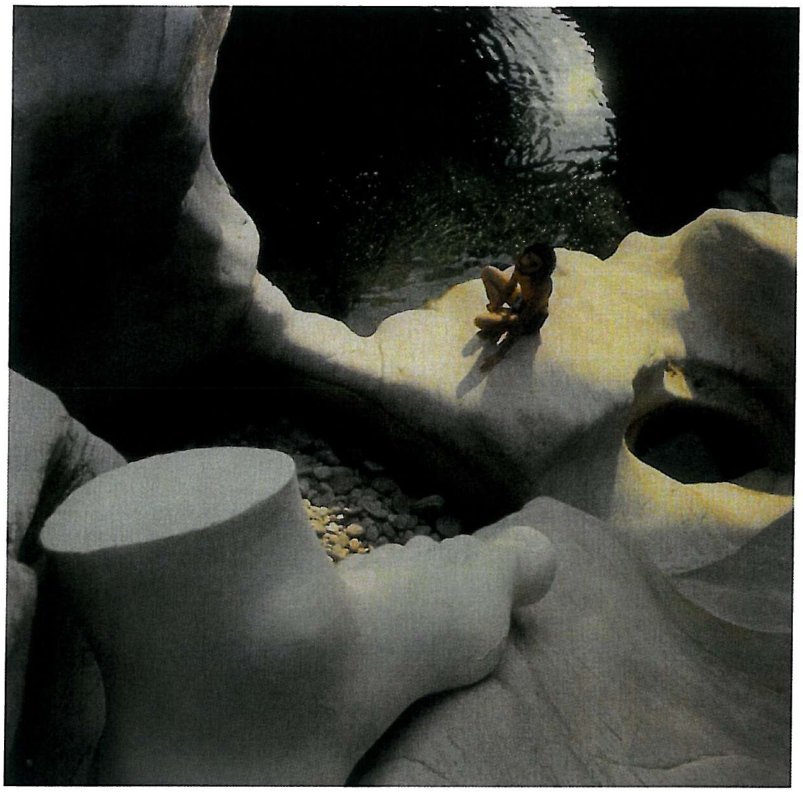
sculptures is shared and expressed by Julien Hébert in the following 1982 quote displayed on the wall of the Musée National des Beaux-Arts du Québec under his 1951 *Contour* garden chair.

> 'I think a chair is a sculpture in the middle of the room. I don't believe that can be doubted. The meaning of the chair's form is also present as real as the meaning of an abstract sculpture, for example. When sculpture represented something, we might have been able to think otherwise, of course. But now there is really no problem. A chair is a sculpture. It is a form in space.'

If a twentieth century chair is a form in space and that form has changed with the passage of time then its original form needs to be returned in the conservation process. The assertion is particularly true if taken in light of following point.

▲ Figure 93: *Polyprop* designed by Robin Day in 1962-1963, obviously a chair but not so obviously a sculpture. (Photo – Fiell & Fiell 2002: 53)

▲ Figure 94: *Catenary Group* designed by George Nelson for Herman Miller in 1963 and on 'display' at the Detroit Institute of Arts. (Photo – Greenberg 1999: 32)



◄ **Figure 95:** ***Up 7*** **designed by Gaetano Pesce in 1969, obviously a 'sculpture' but not so obviously a chair. (Photo – Greenberg 1999: 108)**

Particularly, but not exclusively, in the field of modern art there is a strong call to preserve the original intent of the artist when approaching the conservation of any particular piece. It was the artist who designed, created and therefore defined the object in the first place. This original definition is considered fundamental to the understanding of the object and therefore needs to be upheld in the conservation process (Eastop & Gill 2001; Grattan & Williams 1999; Rava et al 2004; Roy & Smith 2004; Wharton et al 1995). When describing the story of the creation of the *Globe* Aarnio (2003) explains that his motivation was the absence of comfortable sitting furniture in his new flat and his goal was to design a big object with a bold new look. In its current condition there is no doubt the chair is still big. But with its sagging fabric it can be argued it looks far from comfortable and bold is not in the list of descriptors which immediately come to mind when trying to paint a visual picture of it. If Aarnio's original intentions are to be conserved the original profile needs to be restored.

Finally, although it was stated that the art historical value of the chair would not be brought into this discussion the last point raises an issue that can not be left unsaid. *Ball* chairs have become a powerful symbol of the sixties and the Pop Art movement. Their bright primary colours, simple geometry based on a circle or sphere, and large size are part of what helps define *Ball* chairs as such a symbol (Eidelberg 1991; Greenberg 1999; Kalha 2003; Sparke 1986). In its current condition the colour and size of the *Globe* are generally unaffected. The geometry is not so untouched. If simple geometry is important to the understanding of the *Globe* as a Pop object and its role as a Pop object is part of what makes it important today then the geometry and thus the profile of the chair needs to be restored.

The past and current practice in the field of upholstery conservation make it clear that restoring the profile of an upholstered piece is a common, accepted approach to the care of such pieces in heritage organizations. The concept that twentieth century furniture and particularly the *Globe* is as much sculpture as it is functional decorative object makes the original shape of the chair essential to its understanding. Aarnio's original intentions for his 'sculpture' called for it to be comfortable and bold and these concepts need to be able to be communicated by the chair. And finally, a sphere that has become the epitome of Pop is no longer such if it has become an amorphous shape. This progression of ideas makes it clear that an ideal approach to the conservation of the *Globe* would include the restoration of its original profile. Thus in order to fully conserve the *Globe* the original materials used it its creation, the way these materials are linked to the design and production processes used in its creation, and the original profile of the chair need to be conserved. In one of the conservation options previously described is there hope that the ideal could become reality?

3.3– Selecting an approach

In the opinion of at least one twentieth century furniture conservator, those conserving twentieth century pieces have a special responsibility. They regularly receive objects which have only been altered from their original condition due to the test of time – not the intervention of human beings. Confronted with this fact, it is the conservator who might make the first human initiated change to a virgin object. Because these objects represent modernity, sleekness and machined perfection the temptation is to return them to a sleek and perfect state. But, in so doing, the viewing public may be robbed of the ability to see an object for what it truly is. This happens because an object that is of a design that could easily be a modern day contemporary, which has been returned to a like new condition, loses much of its ability to communicate the radical fact that it was actually produced 40, 50 or 75 years ago (Klim 1990). Treatment of an object, and especially one that involves the first intrusion on an object should not be taken lightly. Ward (1986) argues that there is indeed an ethical imperative to minimize treatment since each subsequent intrusion moves an object further from its original state.

Any conservation treatment carried out on the *Globe* will be a first intrusion on the object. Such an intrusion, even in the name of conservation, will change the object. A single person or a team of individuals will make a decision about which aspect or aspects of an object to conserve. The conservation will be carried out and in so doing other conservation possibilities, the preservation of other aspects of the object, will be permanently excluded (Viñas 2005). If marks are cleaned away they can never be brought back. If original stitching or adhesive bonds are released these aspects can be reintroduced with new stitching or new adhesive bonds but they can never be original ones again. If original foam is removed and replaced, even if it is retained and returned to the chair at a later date it will never be just as it was before human hands intervened.

Decisions which permanently erase future preservation possibilities should not be taken lightly and perhaps when the decisions call for a first intrusion on an object this is even more the case. But selecting the 'best' method of intervention has never been easy. It is one of the long established, recurrent problems faced by those in the conservation profession. Perhaps in earlier decades the decision was guided by what were perceived to be more black and white principles. Identify the 'true nature' of an object, figure out how to conserve that nature and the right decision has been made. Make sure the treatment is reversible and the right decision has been made. Make sure the treatment intervenes in the object no more then necessary and the right decision has been made. Today however, theorists argue that there are probably a variety of treatment solutions for an object which could be identified as valid. There is never one perfect conservation solution. In order to determine which solution to apply in the conservation process the questions for whom is the object being conserved and what do these people need from the object must to be asked and answered (Eastop 2006; Villers 2004; Viñas 2005).

Here, five approaches to the conservation of the *Globe* and two variations on two of the approaches have been offered as viable solutions. They are viable in the sense that it appears they could be physically and ethically applied to the *Globe*. However, in today's conservation culture it is very possible that each approach could be identified as the best choice for the *Globe* depending on the circumstances at the time of the decision making process. If, as described above, the answer to the question for whom is the *Globe* being conserved is a factor instrumental to determining which approach to take then it needs to be asked in this case and the first level answer to that question is the V & A. The object is in the V & A's care. Broadly, it was collected because it was considered a desirable move to add it to the V & A's collection and it remains in the collection because it continues to serve a purpose for the museum and/or it has not been determined that it would be appropriate to dispose of it. Therefore, if the *Globe* were to be conserved one of the aims of the project would need to be to maintain or improve the ability of the object to serve the museum's purpose. That purpose, as defined in the *V & A Collecting Plan* (Victoria and Albert Museum 2004) is at least three fold. The museum is obligated to make its collection available to the public through exhibitions and a variety of reference facilities. It aims to display both the history of design and contemporary design in order to serve the creative industries and provide inspiration to all audiences. When specifically considering its twentieth century furniture collection, the museum needs to serve the students and scholars who have been and continue to be the primary users of the collection. This further defines the answer to the question of for whom the *Globe* would need to be conserved to include the public who do or will use the museum, the members of the creative industries the museum seeks to inspire and the students and scholars who have historically used the furniture collection.

What students and scholars are likely to need from the object has been made clear in the literature used to support the previous identification of original materials, the process of design and production and the original shape of the *Globe* as three significant aspect of the object. These people need the Globe to look as it did originally without erasing evidence of the original materials or processes used in its production. A conservation plan which responded to these needs is likely to serve the other two groups of people for whom the V & A seeks to provide. A restored form would make the object suitable for a wider variety of exhibitions and therefore more available to the general public. A return to its original shape, the shape that inspired the masses and made the object what it is today, the shape which was at the root of making it a collectible, inspirational design object in the first place, would probably be more likely to serve the members of the creative industries. Thus, for the V & A, the restoration of the chair's original form becomes paramount with the preservation of evidence of the original materials and processes used in its production not far behind. The way forward for the *Globe*, as it exists in the context of the V & A's collection, lies in the selection of a previously identified conservation solution which offers the possibility of restoring form while preserving materials and evidence of design and production processes.

When considering which solution this might be it was immediately clear the first two approaches outlined in Section 3.1, <u>do nothing</u> and <u>slow degradation</u> would make no effort to restore the original form of the *Globe*. Therefore, they were eliminated from further consideration. The third option, <u>support without intervention</u>, would seek to restore the original profile of the chair but it would do so with an external support which in all probability would be very distracting. This approach was not likely to improve the *Globe's* suitability for a wider variety of exhibitions or restore the essence that made it so inspiring in the first place therefore it was eliminated from further consideration as well. This left two possible approaches, conserve the foam and adhesive *in situ* or remove the degrading materials and replace them with new materials, each with two slight variations. All four variations would require the temporary release of at least part of the original stitching or adhesive bonds used to secure the top covers. They would require the development of a way to re-secure the top covers to an understructure in the final stages of the conservation process. However the remove and replace options would also call for the removal of the original foam and adhesive used to upholster the shell of the chair. The conserve foam and adhesive *in situ* options would preserve this original upholstery material. Encasement would do so in a way that added a significant foreign structure to the chair. Re-adhesion would do so in a way that added only new adhesive/consolidant and re-secured fabric to foam in a way that suggests how the original upholstery process would have been carried out. Therefore, re-adhesion was selected as the approach most likely to restore form while preserving evidence of original materials and the original upholstery process and therefore the approach worthy of further research within the defined project.[96]

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[96] At the time of the above described decision making process the idea that the *Globe* might be needed for a new exhibit was only a hypothetical one. However, the chair has subsequently been identified as an object desired for, *Cold War Modern: Art & Design in a Divided World, 1945-1975*, an exhibit which will take place at the V & A in autumn 2008. The restoration of the original form of the chair is definitely part of what is required of the conservation process which will prepare it for the exhibition. Thus perhaps this line of reasoning, which has considered whom the museum serves and how in order to determine the best way to go about conserving one particular object for current and future users has been appropriate in this case. (The details of what would be required of the conservation process were clarified during personal conversations with Christopher Wilk, Keeper of Furniture, Textile and Fashion, Nigel Bamforth, Senior Furniture Conservator, Marion Kite, Head of Furniture, Textile and Frames Conservation, and other conservation and curatorial staff at the V & A during an informal presentation of a portion of this work on 3 July 2007. The presentation was arranged by Dana Melchar, Furniture Conservator and given by the author.)

3.4– A way forward

Thus the conservation approach which would be investigated for the *Globe* was identified with an ultimate goal of determining whether the most appropriate theoretical approach to the conservation of the *Globe*, in its current context, was also a practical one. The approach would seek to re-adhere the original fabric to the original foam but just how it would go about doing so was far from clear. An adhesive which could be used to adhere the two surfaces without causing damage to fabric or foam needed to be identified. How the adhesive would be applied in the first place needed to be determined. Processes which would erase evidence of the original methods used in the manufacture of the chair and its upholstering process would be avoided and if processes could be introduced that clarified these methods they would be used. If successful a conservation protocol would be identified at the end of the process which would offer a way to restore the original profile of the chair making the chair more able to fulfil its role as a design object meant to inspire.

Ideally, when considering how the original materials would be conserved it was decided the degraded adhesive covering the obverse surface of the foam and the obverse surface of the fabric would be left *in situ* as evidence of the adhesive used during the original upholstering of the chair. The adhesive bond securing the foam pads to the fibreglass(?) shell would be left completely intact. The bond between fabric and foam which was still secure behind and beneath the seat cushions would not be disturbed. In order to gain access to the surfaces of the foam and fabric which needed to be re-adhered the original stitching along the outside edge of the chair would be released. If at all possible not all of the stitching would be released and whenever it was the original threads would be left *in situ* as evidence of the original process and materials. When the top cover fabric was ready to be re-stitched in place new thread would be stitched through the original stitch holes whenever possible and the remnants of original stitching would be captured between the existing fabric and foam.

When considering how the original upholstery methods would ideally be preserved some of the details above are obviously relevant. Additionally, and again ideally, the selected adhesive would not be applied to a support fabric but rather directly to the foam and/or top cover fabric as no such fabric would have been used in the original process.

Such an approach was likely to be irreversible with respect to the foam primarily due to its structure and the way an adhesive would penetrate it. However, there would be no way to re-adhere the two surfaces without applying adhesive to the foam so reversibility was identified as acceptably unachievable in this case (Eastop 2006; Rivers and Umney 2003; Viñas 2005).

In terms of physically carrying out the conservation it was assumed that a support for the *Globe* could be constructed which would make it possible to turn the *Globe* upside down during the process. This meant that it could be assumed that conservation techniques could always be applied with the fabric and foam oriented between the conservator and the floor not above the conservator's head or any other position between the two. Thus techniques did not need to be developed and tested in several different orientations.

These specific details would guide the process of experimentation which would seek to determine if re-adhering the original fabric to the original foam was a strong practical as well as theoretical solution for the *Globe*. To some extent it was expected that due to the perceived fragility of the polyether polyurethane foam it might be possible to re-adhere the two surfaces but any bond produced would not last for an appreciable length of time and when the bond failed it would cause significant damage to the foam. If so the re-adhesion approach would prove to be theoretically desirable but inappropriate with respect to its practical application. However, as this was just a supposition and there was no existing work to prove or contradict it the work needed to be carried out. The evidence that materials, design and production process, and shape all needed to be conserved in the *Globe* was overwhelming and re-adhesion offered the hope of conserving all three to the greatest extent. Until it was shown that re-adhesion was not possible the other conservation approaches could not be carried forward on the strongest of ethical grounds.

Chapter 4 – Defining a Specific Experimental Starting Point

With an ideal conservation approach identified as well as the physical limits on the conservation process due to the chair's construction, condition and significance a plan for experimentation could be established. The process would seek to answer the following primary two-part research question: Working within established conservation constraints, would it be possible to re-adhere the original fabric to the original foam in the Globe? If such a bond could be established would it be of an appropriate strength and durability for the identified conservation purpose? In order to answer these questions small samples of foam and fabric would be adhered to each other using a variety of techniques and the resultant bonds would be analyzed in a variety of ways. The process would be carried out in two stages as described in Chapters 5 and 6. However, first a specific starting point for this process needed to be established. That point is defined below with respect to the materials which would be used and methods of application which would be employed to achieve bonds between them.

4.1 - The selection and preparation of test materials

The selection of foam, fabric and adhesives for testing was governed by two overarching factors. First, the defined research was what Viñas (2005) describes as targeted research. The goal was to find a technical solution to a specific conservation problem not the development of scientific knowledge. That technical solution would identify a conservation appropriate way to re-bond two specific materials, the original wool fabric and the degraded polychloroprene based adhesive coated polyether polyurethane foam in the *Globe*. Therefore, in order to make the research directly applicable to the problem, the foam and fabric used in testing needed to replicate the parallel materials in the *Globe*. The second factor was that the selection of test adhesives would be based on strong literature based and/or experiential evidence that each adhesive would bond the two surfaces in question in a manner appropriate to conservation.

Within this framework, another issue central to the selection of foam, fabric and adhesives for testing is the way in which adhesives bond. There are five commonly referenced theories of adhesion: adsorption, chemical, diffusion, electrostatic, and mechanical. All five can play a part in any one particular bond but all five don't necessarily have to play a role. In this particular case, the chemical, mechanical and adsorption theories were likely to be relevant. The adsorption and chemical theories state that adhesive bonds rely on a chemical interaction between the adhesive and the adherend. The mechanical theory states that it is the mechanical interlocking of the adhesive around the rough surface of the adherend that gives strength to a bond. Thus it was likely that both the physical nature of the surface of the fabric and foam needing to be bonded as well as the chemical nature of both were significant. Therefore, there would be a greater likelihood of establishing a successful bond if the adhesives used could interact on a chemical level with degraded polychloroprene based adhesive coated polyether polyurethane foam and wool fabric and could lock around the surface irregularities of the same foam and fabric (Blank 1988; Comyn 1997; Packham 2005).[97]

Replication of the chemical nature of both the foam and fabric in the *Globe* was also important because test samples would be subjected to accelerated ageing during Stage Two of the experimental process (Chapter 6). In order to use the results of these accelerated ageing tests to draw conclusions about what might happen to the *Globe* over time, the materials which would be aged needed to be significantly similar if not identical to the materials in the *Globe*.

4.1.1 - The foam

Thus foam which matched the chemical nature of that in the *Globe* needed to be found. The physical nature of the surface of this foam also needed to match the physical nature of the previously adhered surface in the *Globe*. Additionally, it was expected that foam density, the existence of open or closed cells in the foam and the existence or lack of a skin on the surface of the foam, resulting from the use of a manufacturing mould, would affect how the foam absorbed adhesives which were applied to it. Therefore, attention to these properties would also be necessary when selecting foam material for the testing process.

The 2CM foam which has been thoroughly described in Chapter 1 was an obvious possible source for this material. It was chemically very similar to the foam in the

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[97] These theories also support the explanation is Section 2.4.2 regarding why polychloroprene would have been an excellent choice of adhesive for the *Globe* in the first place.

Globe. Likewise, there was every reason to conclude that the physical nature of the two materials was equally similar. However, its use would have significant implications on the experimentation process as there was a finite amount of 2CM foam available and consequently a limited number of samples for testing. Artificially ageing new polychloroprene based adhesive coated polyether polyurethane foam in order to produce an acceptable test material available in theoretically unlimited supply was considered. However, no standard procedure existed for producing such material and time and knowledge were limiting factors with respect to undertaking efforts to produce such material. Therefore the idea was not pursued. Thought was also given to using new foam for the initial stages of testing in order to increase the total number of samples available for the process. However, this was decided against as experience with adhesives on different surfaces as well as the theories of adhesion described above make it clear that the nature of the surface to which the adhesive is applied makes a significant difference.[98] Therefore a decision was made to use the 2CM foam with the knowledge that experimentation would have to be carefully designed to insure the number of necessary samples could be produced before the available foam ran out.

In order to prepare the foam for testing both top covers were removed from all five pads as well as any yarns left behind following the removal. No other surface cleaning was e carried out which e insured the degraded polychloroprene based adhesive remained on the obverse surface of the foam along with a few fibres from the original top cover. The pads were then cut into blocks of four specific sizes.[99] A hot wire cutter, Janik Pyrocutter and Transformer Model G4, was used to accomplish this task as it proved to cut through the foam smoothly and evenly without melting excess amounts of foam (Figure 96).[100]

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[98] Personal conversation with Kathryn Gill, Senior Conservator/Lecturer, TCC, University of Southampton

[99] The specific sizes are identified in the following pages when each relevant stage of testing is discussed.

[100] Two other tools were tested when devising a method for cutting the foam. A pair of Mundial upholstery scissors with 12 cm blades (498-10NP-KE) cut the foam quite easily but achieving a consistently straight edge that was perpendicular to the obverse surface of the foam proved to be a challenge. A hot knife, Thermocutter ZTS-20, proved to melt significant amounts of the foam rather than cut cleanly through it.

◄ Figure 96: A portion of one of the 2CM pads being cut to size with the Janik Pyrocutter. Straight edge guides have been placed in parallel above and beneath the foam and the glowing hot wire can just be seen pressing against the top straight edge as the wire cuts through the foam. (Photo – M. Halliwell)

4.1.2 - The fabric

Like the foam, fabric which matched both the chemical and physical nature of the top cover fabric on the *Globe* needed to be found and, as with the foam, the 2CM pads proved to be the obvious first choice. As detailed in Chapter 1, the 2CM foam pads were donated with two top covers still attached and the inner most covers proved to be identical, in all but colour, to that on the *Globe*. However, the outer most top covers had been secured to the inner most ones with a liberally applied adhesive which had completely saturated the inner most covers in many locations. This condition made most of the inner most top covers unusable as both the chemical and physical nature of the covers was altered by it. However, half of one top cover and small portions of three others were able to be salvaged with careful mechanical removal of the additional adhesive from areas where the adhesive had not penetrated the fabric beyond the obverse surface. This fabric was reserved for the final round of testing (Sections 6.3.4 and 6.3.5) and a surrogate fabric was found for all other rounds.

In selecting a surrogate fabric two characteristics were identified as the most important factors: fibre content and weave structure as it relates to durability and particularly elongation. Fibre content because the adhesives which were going to be tested would bond to the fibres due to two primary forces – chemical and physical. Thus something chemically and physically similar to wool needed to be found – another wool fabric. Weave structure because the samples would be evaluated by pulling the bonded fabric away from the foam. A weave structure that was significantly more elastic or stiff than that of the fabric on the *Globe* was not likely to respond to planned tests in a way that would give directly applicable results.[101] The search for such a fabric proved difficult (Section 2.4.1). 100% wool fabrics could be found but all proved to be produced with finer yarns and often different weave structures to that on the *Globe*. Plain weave fabrics with a weave count similar to that on the *Globe* could also be found but invariably they contained a synthetic element in the fibres. In the end a compromise had to be made. A 100% wool fabric woven with a finer yarn and a different weave pattern but with a similar handle to that on the *Globe* was selected.

In order to prepare the surrogate fabric for testing 1612 g of it was scoured in 17 litres (l) of softened water and 17 millilitres (ml) of Dehypon LS45. The wool was placed in the water and detergent mixture at room temperature and then slowly brought to 40 °C. The mix was maintained at 40 °C for 10 minutes and then the fabric was rinsed in progressively cooler water baths. Once cool the fabric was laid out to dry taking care that warps and wefts were well aligned. As it was not obvious, an obverse and a reverse of the fabric were assigned and the reverse surface was identified as the surface which would be adhered in all testing. The fabric was then cut along warp and weft to produce samples of four specific sizes.[102]

4.1.3 - The adhesives/consolidants

Unlike the foam and fabric, the selection of adhesives/consolidants for testing was not based on the need to match existing materials in the *Globe*. It was based on the need to find materials which were likely to bond wool fabric and degraded polychloroprene based adhesive coated polyether polyurethane foam in a manner appropriate for conservation. Conservation research and treatment literature which reported findings regarding the use of adhesives/consolidants on polyether polyurethane soft foam[103] was used as the initial source for identifying such adhesives. A search of this literature produced a list of possible test adhesives/consolidants each of which was then further

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[101] Personal conversation with Peter Fuller, Area Sales Manager, Instron Corporation on 13 January 2006

[102] The specific sizes are identified in the following pages when each relevant stage of testing is discussed.

[103] Butzer 2002; de Jonge 1999; Gill 2001; Grattan & Williams 1999; Kessler 2004; Lorne 1999 & 2004; Ramel & Salles 2004; Rava et al 2004; Sale 1995; van Oosten 1999; van Oosten 2004; van Oosten & Keune 1999; Vandenbrouck 2004; Winkelmeyer 2002

scrutinized for its ability to meet two further criteria. Each selected adhesive/consolidant needed to be able to be prepared and applied using no solvent or suspension medium other than water and reactivated with heat rather than a solvent.

These additional criteria were set primarily because conservation literature strongly warns about the unpredictability of the way solvents react with new and degraded plastics including polyurethane soft foams (Grattan & Williams 1999; Lorne 2004). A plastic which is theoretically inert to a particular solvent may actually react to that solvent due to the presence of a plasticizer, another additive, or the affects of degradation on the plastic in question (Blank 1988; Sale 1988). Due to this unpredictability, the use of a solvent to thin an adhesive/consolidant prior to application or reactivate it once applied was not considered desirable. Such use for reactivation purposes could be avoided by completing the adhesion process before the adhesive dried, completely avoiding the need for any reactivation, or using adhesives which could be reactivated with heat rather than solvents. It is true that heat accelerates the rate of polyurethane degradation (Kerr & Batcheller 1993; Petrie 2004; van Oosten 1999) however the use of low level heat which would be present for only a short time was considered preferable to the use of a solvent which might take months to fully evaporate (Blank 1988). Avoiding the use of a solvent or suspension medium to dilute an adhesive/consolidant to a concentration appropriate for application was not possible. It has however been suggested that limited contact with water has no effect on polyurethane foams no matter what the degree of oxidation (Lorne 2004). Therefore, even though it is known that polyurethane degrades at faster rates when exposed to high levels of humidity (Kerr & Batcheller 1993; Petrie 2004; van Oosten 1999) it was decided that water was the solvent/suspension medium most likely to cause the least damage. Thus only adhesives/consolidants which could be diluted with water would be investigated.

This selection process produced the following list of six adhesives/consolidants which might be used in the initial stages of testing:

- Beva® 371 Film (Beva) – a polyvinyl acetate
- Impranil® DLV Dispersion (Impranil) – a polyurethane
- Isinglass – a protein
- Lascaux Acrylic Adhesive 360 HV (Lascaux) – an acrylic
- Plextol® B-500 (Plextol) – an acrylic
- Primal B-60 (Primal) – an acrylic

Keeping in mind the fact that the selected test foam limited the total number of samples available for experimentation it was decided to eliminate one of the three acrylic adhesives/consolidants from the process. Lascaux and Plextol could be ordered directly from a United Kingdom (UK) conservation resource supplier. Primal could not.[104] As no other more treatment oriented reason to eliminate one over the other could be determined ease of access became the determining factor and Primal was eliminated.

This final list of five adhesives/consolidants was validated by the fact that Horie (1995), Houwink & Salomon (1967) and Shields (1984) all agree that acrylics, polyurethanes, polyvinyl acetates and/or proteins are theoretically appropriate chemical classes of adhesives/consolidants for polyurethane foam and/or wool fabric. Additionally, while Impranil and Plextol were new to the author Beva, Isinglass and Lascaux were familiar textile conservation adhesives/consolidants. This introduced a certain level of prior knowledge with respect to adhesive/consolidant behaviour which was expected to be useful when experimenting with concentrations, application techniques and reactivation techniques.

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[104] In 2006 when the selection of test adhesive was being made.

4.2 – Starting points for the bonding process

Two different approaches would be taken in the process of trying to bond the test fabric to the test foam with the above adhesives. The first was based on Lorne's (1999) work which used gauze impregnated with Lascaux to support tears in degraded pieces of foam. Because the adhesive remains slightly tacky once dry she had been able to stick the dry, adhesive impregnated gauze to fragile, damaged foam without the use of heat or a solvent to reactivate it. This raised the idea that if a tacky stage could be identified in the drying process of any of the test adhesives that stage could be used to achieve adhesion between fabric and foam. If successful the process would accomplish the adhesion of fabric to foam without the use of heat or a solvent other than water which has been described as ideal (Section 4.1.3).

The second approach was based on adhesive application techniques common to textile conservation. Adhesive is often applied to a support fabric and left to dry. Once dry the adhesive coated support fabric is adhered to a textile in need of support by bringing the adhesive coated fabric and the textile into contact and reactivating the adhesive with solvent or heat. Here, the foam would act as the support fabric. Adhesive would be applied to its surface and allowed to dry. Once dry fabric would be placed on the adhesive coated foam and heat would be applied to the fabric in order to reactivate the adhesive beneath.

In both cases it was expected that applying the adhesive to the foam surface would consolidate and strengthen it. The intent was that it would strengthen the foam enough to support the fabric but not strengthen the foam surface so much that the foam just below the consolidant would become vulnerable. By adhering the fabric directly to the foam rather than using a support fabric as little new material as possible would be added to the foam and fabric structure as it exists in the *Globe*. This would alter the chair's original construction as little as possible. If a bond could be established between the two surfaces the goal was to make it strong enough to support the fabric but not so strong that it would induce damage in the foam or fabric before actually failing at the foam/fabric interface.

4.2.1 - Adhesive application

Four of the five adhesives which had been selected for testing would need to be applied to foam in liquid form. Such an adhesive could be applied to a foam surface with a sprayed or brushed technique and in this case a brushed technique would be used as the experimental starting point. Some argue quite strongly that a sprayed technique, in the form of nebulising, is preferable because it coats the foam without filling the open cells which in turn reduces the stiffening affect the adhesive has on the foam (Vandenbrouck 2004; Winkelmeyer 2002). However, in an upholstered environment where fabric, plastic, wood and other materials are likely to be adjacent to the foam to which adhesive would need to be applied a brushed technique was expected to be much more easily controlled and thus worthy of investigation.

A 10 mm wide brush was used to apply the adhesive and initially three brush stroke patterns were tested: a one stroke, a two stroke and a multiple stroke technique. The one stroke technique applied adhesive to the foam surface using single strokes, adjacent to each other and always applied in the same direction. The two stroke technique initially coated the foam using the one stroke technique and then immediately recoated it with a one stroke technique in the reverse direction. The multiple stroke technique coated each section of the foam surface using short strokes of 1 to 2 cm applied in the same direction one on top of the other. The strokes were applied until the surface of the foam appeared completely covered by adhesive which usually took four strokes.

4.2.2 - Adhesive concentrations

The four adhesives which would be applied as above also needed to be prepared at initially undefined concentrations. The starting points for experimentation were eventually set based primarily on the upper and lower limits of the concentrations identified as useful in the conservation literature previously discussed (Lorne 1999; Rava et al 2004) with some modifications based on the author's previous experience. They were prepared on a weight to volume (w/v) basis in all cases. They were:

Impranil[105]	50% w/v in deionised H_2O 100%
Isinglass	4% weight dry swim bladder/volume deionised H_2O 10% weight dry swim bladder/volume deionised H_2O
Lascaux[106]	15% w/v in deionised H_2O 50% w/v in deionised H_2O
Plextol[107]	50% w/v in deionised H_2O 100%

Additionally it was decided that Beva film would be tested at both thicknesses at which it could be supplied: 25 µm and 65 µm.

4.2.3 - Reactivation temperatures and times

Whether initially applied to the foam in liquid form or as a film, all five test adhesives would need to be reactivated when testing methods for adhering fabric to the adhesive covered foam. Again starting points for testing were set (Table 2) using a combination of literature sources and practical experience.[108]

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[105] Supplied as a dispersion of 40% solids in water

[106] No information regarding solids content available from the manufacturer. But Lascaux is reportedly supplied as a dispersion of 48% solids in water. (http://cameo.mfa.org/materials/record.asp?MaterialName=acrylic&Search=Search&key=2170&subkey=5264)

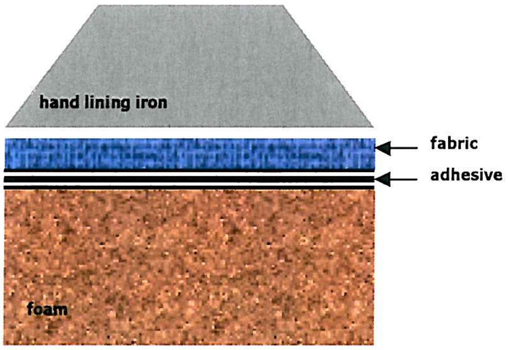
[107] Supplied as a dispersion of 50% solids in water

[108] Based on conversations with Anne Kvitvang and Karen Thompson, Textile Conservators at the TCC, experience during teaching sessions during the author's MA Textile Conservation at the TCC and product literature supplied by Conservation by Design Limited and Bayer Material Science.

Table 2: The reactivation parameters which were used as the starting points during the testing process.

Adhesive	Reactivation Temperature in °C	Reactivation Time in seconds (s)
Beva	75	5 – to tack the film to the foam 10 – to reactivate the adhesive through the fabric
Impranil	85	15
Isinglass	60	10
Lascaux	80	10
Plextol	65	10

Initially all heat reactivation would be carried out with a Willard Hand Lining Iron using a type 'E' monitor and controller with and 8E (MIN) iron. Samples would be oriented as in Figure 97 with the foam on the bottom, iron on top and the adhesive and fabric in between. This would replicate the orientation in which the process would be carried out if actually applied to the *Globe*, as described in Section 3.4.



◄ **Figure 97: The orientation of foam, adhesive, fabric and hand lining iron during the testing process.**

4.2.4 – Laboratory conditions

Unless otherwise noted all work was carried out at ambient temperatures in the analytical laboratory and conservation workrooms at the TCC: 21 +/- 4 °C and 48 +/- 24% relative humidity (RH).

4.3 – Testing the starting points

In order to evaluate whether or not the starting points described above (Section 4.2) achieved a level of success which would validate them as appropriate starting points for Stage One (Chapter 5) of the experimental process an initial round of testing was carried out. 28 samples were prepared by cutting 7.5 cm x 4.0 cm x 1.0 cm blocks of foam and 8.0 cm x 4.0 cm pieces of the surrogate fabric. Adhesive would be applied to the 7.5 cm x 4.0 cm surface which was a cross-section of the foam pad rather than the obverse surface to which the degraded adhesive was still attached. It was accepted that the use of this surface was likely to provide results that would be somewhat different from those obtained in later rounds, when the adhesive coated surface would be used. However, by using the 2CM foam in this way in the early stages of experimentation a sufficient number of samples could be cut and the ideal number of tests could be carried out. Adhesives were applied to the foam samples using the concentrations and application techniques detailed in Table 3. If the adhesive was applied in liquid form the drying process was monitored in order to determine if a tacky stage in the process could be identified. Once dry[109] each sample was evaluated in order to consider how the application of an adhesive changed the nature of the foam. 48 hours after adhesive application efforts were made to adhere the fabric samples to the adhesive coated foam surfaces starting with the reactivation parameters previously outlined. Once the reactivation process was complete the fabric was manually peeled from the foam in order to evaluate the quality and strength of any resultant bond. The results of this initial round of testing were used to redefine the starting parameters for Stage One (Chapter 5) of the experimental process and establish systems for evaluating the samples which would be produced.

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[109] The point at which an adhesive was considered dry was when all evidence of a milky and/or moist surface had disappeared and the surface felt dry to the touch. It is possible that this point is not actually when the adhesive reached a completely dry state but it was the point used to represent dryness in these experiments. Additionally, apparent dryness does not necessarily correlate to a completely cured state.

Table 3: Samples prepared to test the selected starting parameters for Stage One of the experimental process.

Sample #	Adhesive Type	Concentration	Application Method
500	Lascaux	15% w/v	1
501			2
502			M
503		50% w/v	1
504			2
505			M
506	Plextol	50% w/v	1
507			2
508			M
509		100%	1
510			2
511			M
512	Isinglass	4% w/v	1
513			2
514			M
515		10% w/v	1
516			2
517			M
594	Impranil	50% w/v	1
595			2
596			M
597		100%	1
598			2
599			M
518	Beva	25 µm	T
519			T
520		65 µm	T
521			T

Legend:

Application method: ***1*** = one brush stroke; ***2*** = two brush strokes; ***M*** = multiple brush strokes; ***T*** = Tacked with heat

4.3.1 – Summary and results of the testing process – identifying a tacky stage

In order to determine whether or not any of the liquid adhesives passed through a tacky stage as they dried the adhesive coated surface of each foam sample was monitored with light finger pressure every five to ten minutes. Monitoring started five minutes after application and continued until the sample was dry. The process determined that six of the 28 samples had passed through a recognizable tacky stage in the drying process:

- Three samples prepared with Plextol at 100%.
- One sample prepared with Isinglass at 4% w/v.
- Two samples prepared with Isinglass at 10% w/v.

4.3.2 – Summary and results of the testing process – a change in the foam's nature?

In order to begin considering whether the application of adhesives to the surface of historically significant upholstery foam changed the nature of the foam so much it was no longer worth conserving,[110] each sample was examined once the applied adhesive had dried. This examination was also carried out to begin considering whether the application of one or more specific adhesives changed the nature of the foam in a way that would suggest a particular adhesive should not be used in the identified conservation process. Finally the examination would help determine whether the use of a sprayed application technique rather than a brushed one should be investigated (Section 4.2.1).

A variety of altered characteristics were observed and recorded in the following very general terms. When the adhesive coated surface of the foam was slightly compressed with a fingertip it took longer for the Lascaux and Plextol coated samples to recover their original form than any of the other samples or an uncoated piece of foam. The higher concentrations of Impranil, Isinglass and Plextol deposited particularly thick films on the foam surface. The Beva and Isinglass coated surfaces became very shiny while an uncoated surface was quite mat. The higher concentration of Isinglass turned a soft and flexible foam surface into a rather brittle one. Two of the eight samples which

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[110] A possibility raised by Scott Williams, Senior Conservation Scientist, CCI during a personal conservation on 10 June 2004.

had been coated using the multiple brush stroke technique showed evidence that the adhesive had penetrated deeper into the foam than on any of the other samples.

4.3.3 – Summary and results of the testing process – the reactivation process

Although the above starting points had been identified regarding reactivation parameters for each adhesive being tested, in practice the time and temperature that was originally selected based on literature sources and previous experience was only used for Lascaux - 15% w/v. The three samples for which this adhesive and concentration were used were the first samples with which adhesion by reactivation was tried. The selected starting temperature was in the middle range of those used in the author's previous experience and the concentration at which the adhesive was prepared was at the high end of experiential knowledge. It was therefore expected that while a perfect bond might not be established between the two surfaces some type of bond was expected. In practice however no bond was produced. In trying to determine why, it was hypothesized that the thick wool fabric was acting as a heat barrier for the adhesive film and that perhaps a longer period of time was needed to allow the heat to penetrate through the fabric to the film. The reactivation time was lengthened to in the end 100 seconds with still almost no adhesion being achieved. With this information it was then hypothesized that the nature of the way the foam surface absorbed the adhesive was perhaps also playing a part in the way the adhesives were or were not responding to the applied heat. Additionally, perhaps the surface of the heavy wool fabric had qualities which prevented it from making the type of contact with the adhesive which would be necessary to produce a bond. Slightly more success was achieved with Lascaux - 50% w/v at the longer reactivation times but still not the type of success that was expected based on experience with the adhesives. It was then considered that perhaps too much heat had been applied and the adhesive had been pushed into the foam rather than softened and bonded to the fabric. However, with the Lascaux - 50% w/v sample a substantial film was still present on the surface of the foam following reactivation attempts so this theory was determined to be in all probability invalid. Clearly, bonding fabric to foam was going to be different than bonding two textiles.

In the end the reactivation times and temperatures for all of the adhesives being tested were adjusted from the previously identified starting points. Table 4 details the originally identified starting points and the times and temperatures eventually tested. The upper limit of both the temperature and time tested for each adhesive represents the point where some level of acceptable adhesion was achieved or testing was abandoned as there was no sign adhesion would be accomplished with the defined process.

Table 4: The initially selected reactivation time and temperature for each adhesive type and concentration as well as all the reactivation times and temperatures eventually tested.

Adhesive Type and Concentration	Selected Starting Reactivation Temperature and Time	Tested Reactivation Temperatures in °C	Tested Reactivation Times in seconds
Beva – 25 µm	Tack at 75 °C for 5 s Reactivate at 75 °C for 10 s	75	Tack10 Reactivate 30 -- Tack 10 Reactivate 60
Beva – 65 µm			
Impranil – 50% w/v	85 °C for 15 s	85	15 90
Impranil – 100%			
Isinglass – 4% w/v	60 °C for 10 s	60	60 120 180
Isinglass – 10% w/v		80	120 150 180
Lascaux – 15% w/v	80 °C for 10 s	80	10 30 60 100
Lascaux – 50% w/v		80	30 60 100
Plextol – 50% w/v	65 °C for 10 s	65	30 60
		75	60 120 180
		85	120
		95	180
Plextol – 100%		85	120
		95	120 180 300

4.3.4 – Summary and results of the testing process – bond evaluation

Once the above reactivation process was complete the fabric was manually peeled from the foam surface. As the fabric was pulled away the strength of the bond was considered keeping in mind the goal that the bond should be strong enough to support the fabric in the *Globe* but not so strong that it would induce damage in the foam or fabric before actually failing at the foam/fabric interface. Each bond was qualified with one of four strength of bond descriptors: no adhesion < slight adhesion < stronger adhesion < probably strong enough (Table 5).

Table 5: The results of the bond strength evaluation of each sample produced in the initial round of testing. Unless otherwise noted each adhesive/concentration is listed at the greatest strength of bond it managed to produce and that bond was produced with the greatest temperature and time listed in Table 4.

No Adhesion	Impranil – 50% w/v Impranil – 100% Isinglass – 4% w/v Isinglass – 10% w/v
Slight Adhesion	Lascaux – 15% w/v Plextol – 50% w/v
Stronger Adhesion	Beva – 25 µm Beva – 65 µm – reactivated at 75 °C for 30 s Lascaux – 50% w/v Plextol – 100%
Probably Strong Enough	Beva – 65 µm – reactivated at 75 °C for 60 s

4.4 – Resetting the starting points

The above testing process clearly showed that the starting points initially selected for the two stage experimental process needed to be adjusted. Many of the adhesives exhibited no tacky stage in the drying process and therefore the investigation of how such a stage might be used would have to be limited to the adhesives which did. Heat reactivation of the applied adhesives, even after significant adjustments of the starting parameters for temperature and time, had produced only one bond which appeared to be of a sufficient strength. Thus further consideration would need to be given to how the bonding process could be adjusted to achieve greater strength. Some changes to the nature of the foam surface due to the application of an adhesive had been recorded and how these changes would influence the experimental process needed to be determined.

4.4.1 – The use of a tacky stage in the drying process

Isinglass – 4% w/v, Isinglass – 10% w/v and Plextol – 100% would be further investigated with respect to utilizing a tacky stage in the adhesive drying process to adhere fabric to foam. All other adhesives/concentrations would be eliminated from this element of the testing process as they had exhibited no such tacky stage. Of particular note in this decision is the fact that although Lorne (1999) had found dry Lascaux tacky enough to adhere gauze to fragile foam and the product literature provided with the adhesive indicates it will remain tacky above 0 °C, when applied to the foam surface being tested in this work the surface had no more appreciable tack than any of the other films and certainly not enough to adhere fabric to foam.

4.4.2 – Reactivation with heat

The results regarding the strength of bonds produced with heat reactivation, as presented in Sections 4.3.3 and 4.3.4, showed that only Lascaux - 50% w/v, Plextol – 100% and Beva at both thickness achieved a strength qualified as 'stronger adhesion' or above with only 65 µm Beva reactivated at 75 °C for 60 seconds achieving a strength of 'probably strong enough'. However, the 'probably strong enough' Beva bond also damaged the foam surface as the sample was peeled apart where the Lascaux, Plextol and Beva bonds qualified as 'stronger adhesion' caused no damage to fabric or foam in the peeling process. In considering how the heat reactivation process might be adjusted to achieve a greater level of success with respect to acceptable bond strength and quality three possibilities presented themselves.

The first had to do with the fact that in this initial stage of testing no thought had been given to how long an adhesive should sit before reactivation and in most cases the adhesives sat for 48 hours after application before reactivation. Perhaps if an adhesive was reactivated just after it reached dryness[111] a stronger bond between fabric and foam could be produced. As Lascaux – 50% w/v and Plextol – 100% were the only liquid adhesive which in initial testing had achieved a strength of adhesion greater than slight they would be used in Stage One to test this hypothesis.

The second possibility also had to do with a slight adjustment to reactivation parameters already tested. There were four Beva bonds produced in initial testing. Three had not been quite strong enough but they had caused no damage to fabric or foam when pulled apart. The fourth appeared to be strong enough but it had caused damage to foam during the peeling process. Would an adjustment of tacking and/or reactivation time and/or temperature strengthen one of the weaker bonds enough to achieve acceptable adhesion without strengthening it so much that it induced the type of damage caused by the strongest of the four Beva bonds? This question would be answered by an adjustment of the reactivation parameters used for Beva bonds in Stage One.

The third possibility would introduce an adjustment to the approach to adhesion rather than just an adjustment of the reactivation parameters used. The fact that the 65 μm Beva reactivated for 60 seconds bond was 'probably strong enough' but at the same time not of a quality that protected the foam surface as the bond failed raised the question of whether or not it would be possible to protect the foam surface prior to adhering Beva to that surface. This hypothesis was quickly tested with two samples. Beva – 65 μm was tacked at 75 °C for 10 seconds to one of the Lascaux - 50% w/v samples and one of the Plextol - 50% w/v samples. Then, with fabric in place, the samples were reactivated at 75 °C for 60 seconds. It was hoped that by using Beva and

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[111] As identified in Section 4.3

another adhesive in combination any resulting bond would retain the strength of the previous Beva bond but cause no damage to fabric or foam when peeled apart. This is exactly what happened with the sample involving Plextol - 50% w/v but damage was caused to both foam and fabric in the Lascaux – 50% w/v sample. With very promising results in at least one sample, the approach of using Beva in combination with another liquid adhesive was identified for further investigation in Stage One.

4.4.3 – Adhesive application by brushed techniques

Although examination of the samples following the adhesive application process showed that in most cases the character of the foam surface was at least somewhat altered by the process no alteration was considered so drastic that testing with one or all adhesives should be halted. The alterations were generally what could have been predicted from literature and experiential evidence and therefore not a surprise. A film of varying thickness, shine and continuity was deposited on the foam surface. This film occasionally made the foam surface more brittle and sometimes slowed its ability to recover from a momentary compression. Because one of these alterations, or an as yet unidentified one, might eventually be used as a determining factor for retention or elimination in the later stages of experimentation they would continued to be monitored. For Stage One a slightly more specific form of evaluation would be used.

Likewise there was not yet any clear reason to eliminate a brushed application technique and the benefits it offered in terms of ease of controllability still seemed very desirable. Along similar lines no clear reason presented itself for selecting one of the three brush stroke patterns tested over another. However, in order to reduce test variables it was considered ideal to begin to do so. Notes written during the actual brushed application process indicated that the one stroke technique seemed to leave more areas of the foam surface uncoated in adhesive than the other two techniques. In two cases the multiple stroke technique appeared to have pushed adhesive further into the foam sample than in all other cases. These two factors suggested that perhaps the two stroke technique had the potential to be most consistent. Therefore, the first round of Stage One would be designed to include a greater percentage of samples prepared with this technique in order to gather a larger amount of data regarding its suitability for the presented task.

4.5 – Conclusion

Thus, an initial round of testing had moved knowledge regarding adhering 100% wool fabric to naturally aged polyether polyurethane foam away from primarily text based details and experience based hypotheses. A small amount of research based knowledge was now available. This knowledge made it possible to redefine the experimental starting points for Stage One. Those starting points now stood on a much a stronger foundation. The work which would seek to determine whether or not, working within established conservation constraints, it would be possible to re-adhere the original fabric to the original foam in the *Globe*, could move forward.

Chapter 5 – Experimental Stage One: Is Re-adhering the Original Fabric to the Original Foam Possible?

Stage One of the formal experimental process would seek to determine whether an apparently successful bond between test fabric and test foam could be produced. That successful bond would be of a strength which would support the top cover fabric in the context of the Globe without being of a strength and quality that would cause damage to foam and/or fabric if the bond failed. The stage was carried out in two rounds. Round One identified several foam/adhesive/fabric combinations which did result in bonds of at least apparently sufficient strength. Round Two considered whether those bonds were not just of sufficient strength but also of appropriate quality.

5.1 - Introduction

Initial testing had revealed that before investigating whether or not bonds between 100% wool fabric and naturally aged polyether polyurethane foam were of a conservation appropriate strength first more work needed to be done to find ways of merely bonding the two surfaces with the identified conservation appropriate materials. That work would begin with both the adjustment of previously mildly successful reactivation parameters and the initial testing of other approaches to the adhesion process. Achieving success, work would move on to determine whether any of the resultant bonds not only proved to be of apparently reasonable strength but also appeared to cause little or no damage to fabric or foam when the bond was peeled apart.

5.2 – Methods of testing and evaluation

The general approach to experimentation would be what was established in the initial testing process. Attempts would be made to adhere test fabric to test foam using a variety of adhesive concentrations and adhesive application and reactivation methods. Once adhered the fabric would be manually peeled from the foam surface. During the process data needed to consider the amount of liquid adhesive applied to each sample and the drying time of each adhesive would be recorded. Changes in some qualities of the foam samples following adhesive application would be monitored. The strength of any resultant adhesive bond would be evaluated and any damage done to fabric and/or foam in the process would be noted. Primarily rough qualitative methods of evaluating the samples during the process would be used with the end goal being the identification of one or more foam/adhesive/fabric combinations worthy of being carried forward into the second stage of experimentation. That stage would evaluate promising solutions on a quantitative basis.

5.2.1 – Recording quantity of adhesive applied and drying time

The mass of each sample and one length and one width measurement of the surface to which adhesive was to be applied were recorded at the start of testing. Immediately following adhesive application the mass of each sample was recorded again. These details were used to calculate the average mass per square centimetre of adhesive applied to each sample.

The time of adhesive application was recorded as was the time the adhesive reached a point were all evidence of a milky and/or moist surface had disappeared and the surface felt dry to the touch. These details were used to determine the average length of time it took each adhesive type and concentration to reach the point established as the marker of dryness (Section 4.3).

5.2.2 – Evaluating the dry adhesive film coated foam samples

From the list of altered characteristics of the adhesive coated foam samples noted during the initial testing process five were identified for inclusion in the monitoring process for at least Stage One: Round One. They were determined to be characteristics which might either affect the bond producing capabilities of the adhesive coated foam surface or change the nature of the foam in a way that was considered inappropriate with respect to the conservation of the *Globe*. The evaluated characteristics and the generally qualitative classifications used to distinguish the extent of change in each sample are outlined in Table 6. The classifications represent, for the most part, general categories rather than specific categories with hard and fast boundaries which could be monitored by quick and uncomplicated means. This was ideal for the early stages of experimentation as the general purpose of the evaluation was to determine whether or not any particular characteristic changed the foam in a way that called for more detailed, quantifiable evaluation.

Table 6: The characteristics of the adhesive coated foam samples which were monitored following the drying process of the liquid adhesives.

Characteristics	**Classifications** (Abbreviations)
Time to full recovery from a momentary fingertip compression of approximately 5 mm	Immediate
	Less than 1 second
	1 to 2 seconds
	2 to 5 seconds
	More than 5 seconds
Apparent thickness of the adhesive film on the foam surface	Almost not detectable (AND)
	Light film (Light)
	Medium film (Medium)
	Heavy film (Heavy)
Quality of the adhesive film with respect to continuity	Not able to determine with the naked eye (NATD)
	Very incomplete (VI)
	Holes primarily larger than a cell with a few cell sized holes (HPLC)
	Holes primarily cell sized with a few larger holes (HPCS)
	Basically continuous with holes generally the size of a cell (BCHCS)
	Continuous
Quality of the adhesive film with respect to flexibility	Soft and flexible (Soft)
	Stiff but flexible (Stiff)
	Brittle
Apparent penetration of the adhesive into the foam	Even surface film (Even)
	Below surface in some areas (Below)

In order to establish consistency in the evaluation process all samples evaluated in either Round One or Round Two were laid out on the work bench and evaluated at the same time. Two control samples were also used. Control One was a sample of the foam being used for testing which had not been coated with adhesive. Control Two was a sample of the adhesive coated foam currently used in the manufacture of *Ball* chairs.

Recovery from fingertip compression was determined by lightly compressing the adhesive coated foam with a fingertip to a depth of approximately 5 mm. The pressure was immediately released and the amount of time it took for all evidence of the compression to disappear was recorded. If the recovery was so fast it could not even be seen to happen it was recorded as immediate. All other classifications are self explanatory.

The apparent thickness of the adhesive film was determined by a comparison of all evaluated samples and the baseline that Control One had no film and the thickness of the film on Control Two was identified as medium. Each sample was examined visually, with the naked eye, and physically, by compressing the sample between finger and thumb tip. The compression took place with a finger tip on the adhesive coated surface and a thumb tip below.

The quality of the adhesive film with respect to continuity was determined visually, with the naked eye, by considering the size of any holes in the resultant adhesive film as compared to the size of the cells in the foam beneath. Control One provided a consistent reference with respect to the average cell size in the foam samples.

The quality of the adhesive film with respect to flexibility was determined by a comparison of all evaluated samples and the baseline that both Control One and Control Two were evaluated as soft and flexible. The determination was made using the same finger tip compression used to consider the recovery rate of the compressed surface.

The apparent penetration of the adhesive into the foam was evaluated by compressing a sample between finger and thumb tip as above in order to consider whether the resultant film was evenly distributed on the surface or had some areas where the adhesive penetrated to a deeper depth than the rest of the film. Control Two provided a consistent reference as it was evaluated as having an even surface film.

5.2.3 – Evaluating the strength of resultant adhesive bonds

Once any attempt at establishing a bond between the foam and fabric surfaces had been made the samples were left to sit overnight. Then the fabric was manually peeled from the foam surface at a slow and steady rate. As the fabric was pulled away the strength of the bond was considered with respect to whether or not it felt strong enough to support the top cover fabric within the context of the *Globe*. It was then qualified with one of the strength of bond descriptors used in the initial testing process: no adhesion < slight adhesion < stronger adhesion < probably strong enough.

5.2.4 – Evaluating location and type of damage caused by a manual peel

Following the manual peel the foam and fabric were examined. It was noted whether or not the process had damaged either part of the sample with a category of no obvious damage or damage to foam and/or fabric assigned. Where the bond failed during the peel was also recorded with the following three locations or a combination of them being possible:

- Between the fabric and the adjacent layer of Beva or consolidated foam
- Between the Beva and the consolidated foam
- Within the foam

5.3 – Two rounds of testing

The experimental protocols for both rounds of Stage One were as established in initial testing. Blocks of foam and pieces of fabric would be cut using previously described materials and techniques. Liquid adhesive would be brushed on the foam surface with the same 10mm wide brush using the same variety of brush stroke patterns. Beva would be tacked to the foam surface using the same hand lining iron. Once the foam surface was adhesive covered attempts would be made to adhere fabric to that surface. Again, if required, the same hand lining iron would be used and the orientation of the samples would not change from that described in Section 4.2.3. All work would continue to be carried out at ambient temperatures.

5.3.1 – Round One – the process

For Round One four distinct sets of samples were prepared to test four different hypotheses regarding how 100% wool fabric and naturally aged polyether polyurethane foam might be appropriately adhered. For each set 7.5 cm x 4.0 cm x 1.0 cm blocks of foam and 8.0 cm x 4.0 cm pieces of surrogate fabric were cut. Once again a cross-section of the foam pad would be used as the test surface meaning the degraded adhesive was not yet being considered as part of the adhesion question. However, use of this surface continued to maximize the number of tests which could be carried out in the process of finding a way to merely bond the two surfaces. For each sample which was to be coated with liquid adhesive, one length and one width measurement of the foam surface to which the adhesive would be applied was taken. Then each sample was weighed before and immediately after liquid adhesive application. The drying process was observed and when the applied adhesive appeared to be dry the time it took to achieve this state was recorded. For all samples, once the foam surface was coated with a dry adhesive film the sample was evaluated using the criteria described in Section 5.2.2. Reactivation was then carried out in a variety of ways, as described below. Once each reactivation process was complete the samples were left overnight. The following morning the fabric was manually peeled from the foam and the results were recorded as set out in Section 5.2.4.

Group One - This set of samples was prepared with the primary goal of determining whether heat reactivation carried out immediately after the applied adhesive appeared dry produced stronger bonds between the fabric and foam in question than those produced in initial testing where reactivation took place 48 hours after liquid adhesive application. Lascaux – 50% w/v and Plextol – 100% were used as they were the adhesives identified in initial testing as showing some promise when used as a single liquid adhesives heat reactivated to bond fabric to foam. Lascaux – 75% w/v was also tested to consider whether a higher concentration of the adhesive would improve bond strength. These adhesives/concentrations were applied to previously cut foam as detailed in Table 7. Immediately following the point when the adhesive coated surface was determined to be dry attempts were made to adhere fabric to the adhesive covered surface through heat reactivation. The temperature and time for each of these reactivations was based on the most successful time and temperature used for each adhesive in initial testing and is detailed in Table 7.

Table 7: The samples prepared for Round One, Group One.

Sample #	Adhesive	Application Method	Reactivation Temperature and Time
522	Plextol – 100%	1	95 °C for 300 s
523		2	
524		M	
525	Lascaux – 50% w/v	1	90 °C for 180 s
526		2	
527		M	
528	Lascaux – 75% w/v	1	90 °C for 180 s
529		2	
530		M	

Legend:

Application method – ***1*** = one brush stroke; ***2*** = two brush strokes; ***M*** = multiple brush strokes

Group Two - This set of samples was prepared with the primary goal of determining whether or not an increase in tacking and reactivation times, and reactivation temperatures resulted in a change in the bond characteristics of the Beva only bonds produced in initial testing. The adhesive film was heat tacked to the prepared foam samples, fabric was placed on top of the film covered surface and the sample was heat reactivated. Table 8 details the film thickness, tacking and reactivation temperatures, and tacking and reactivation times used for each sample.

Table 8: The samples prepared for Round One, Group Two.

Sample #	Beva Film Thickness	Tacking and Reactivation Temperature	Tacking Time in seconds	Reactivation Time in seconds
531	25 µm	75 °C	15	90
532				120
533				150
534		75 °C	30	90
535				120
536				150
537		85 °C	15	90
538				120
539				150
540	65 µm	75 °C	15	90
541				120
542				150
543		75 °C	30	90
544				120
545				150
546		85 °C	15	90
547				120
548				150

Group Three - This set of samples was prepared with the primary goal of gathering more information regarding how adhesive type, adhesive concentration and reactivation times might affect a bond formed by using Beva between a consolidated naturally aged polyether polyurethane foam surface and 100% wool fabric. Liquid adhesives were applied to the prepared foam samples as laid out in Table 9. Once dry Beva – 65 µm[112] was heat tacked to the adhesive coated surface of the foam and fabric was adhered to the film with heat reactivation. All tacking and reactivation was carried out at 85 °C and all tacking was carried out for 15 seconds.[113] The time for reactivation varied as described in Table 9.

Table 9: The samples prepared for Round One, Group Three.

Sample #	Adhesive Type	Concentration	Application Method	Reactivation Time in seconds
549	Lascaux	25% w/v	2	90
550			2	120
551			2	150
552		50% w/v	2	90
553			2	120
554			2	150
555		75% w/v	2	90
556			2	120
557			2	150
558	Plextol	25% w/v	2	90
559			2	120
560			2	150
561		50% w/v	2	90
562			2	120
563			2	150
564		75% w/v	2	90
565			2	120
566			2	150
594	Impranil	50% w/v	1	90
595			2	
596			M	
597		100% w/v	1	
598			2	
599			M	

Legend:

Application method – ***1*** = one brush stroke; ***2*** = two brush strokes; ***M*** = multiple brush strokes

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[112] Beva – 65 µm was used for all samples as it was the film thickness which had been used for the preliminary tests of this adhesion method and it had produced results which were somewhat successful.

[113] The parameters of 85 °C and 15 seconds tacking time were used as they were the parameters which consistently achieved an apparently sufficient bond strength in Round One, Group Two.

Group Four - This set of samples was prepared with the primary goal of determining whether the tacky stage identified in the drying process of Isinglass – 4% w/v, Isinglass – 10% w/v and Plextol 100% could be utilized to adhere 100% wool fabric to naturally aged polyether polyurethane foam. Wet adhesives were applied to the prepared foam samples as laid out in Table 10. In this case, as the applied adhesive only reached complete dryness after the fabric layer was applied the adhesive covered surface could not be evaluated. The drying process was monitored as described in the initial testing procedures (Section 4.3.1). Once a tacky stage was reached fabric was applied to the tacky surface and adhesion was attempted in one of three ways.

1. The sample was immediately reactivated.
2. A 73 g glass weight was placed on top of the fabric and the sample was left to dry for a period of time. Then the sample was reactivated.
3. A 73 g glass weight was placed on top of the fabric and the sample was left to dry overnight.

The specific times and temperatures for drying and reactivation are detailed in Table 10.

Table 10: The samples prepared for Round One, Group Four.

Sample	Adhesive	Application Method	Adhesion Method Once Tacky
567	Isinglass – 4% w/v	1	Immediately reactivated at 70 °C for 90 s
568			Covered with a glass weight for 30 min and then reactivated at 70 °C for 90 s
569			Covered with a glass weight and left to dry for approx 21 h
570		2	Immediately reactivated at 70 °C for 90 s
571			Covered with a glass weight for 30 min and then reactivated at 70 °C for 90 s
572			Covered with a glass weight and left to dry for approx 21 h
573		M	Immediately reactivated at 70 °C for 90 s
574			Covered with a glass weight for 30 min and then reactivated at 70 °C for 90 s
575			Covered with a glass weight and left to dry for approx 21 h
576	Isinglass – 10% w/v	1	Immediately reactivated at 80 °C for 90 s
577			Covered with a glass weight for 90 min and then reactivated at 80 °C for 90 s
578			Covered with a glass weight and left to dry for approx 21 h
579		2	Immediately reactivated at 80 °C for 90 s
580			Covered with a glass weight for 90 min and then reactivated at 80 °C for 90 s
581			Covered with a glass weight and left to dry for approx 21 h
582		M	No tacky stage identified so no action taken
583			
584			
585	Plextol – 100%	1	Immediately reactivated at 95 °C for 180 s
586			Covered with a glass weight for 60 min and then reactivated at 95 °C for 180 s
587			Covered with a glass weight and left to dry for approx 21 h
588		2	Immediately reactivated at 95 °C for 180 s
589			Covered with a glass weight for 60 min and then reactivated at 95 °C for 180 s
590			Covered with a glass weight and left to dry for approx 21 h
591		M	Immediately reactivated at 95 °C for 180 s
592			Covered with a glass weight for 60 min and then reactivated at 95 °C for 180 s
593			Covered with a glass weight and left to dry for approx 21 h

Legend:

Application method – ***1*** = one brush stroke; ***2*** = two brush strokes; ***M*** = multiple brush strokes

5.3.2 – Round One – the results

Overall, the testing revealed the following results. The average mass of liquid adhesive applied per square centimetre usually increased with an increase in adhesive concentration or the number of brush strokes used to apply the adhesive. With respect to drying time, Impranil dried the fastest, Lascaux the slowest with Plextol in between. All evaluated samples were altered to varying degrees by the application of Beva, Impranil, Lascaux or Plextol to the foam surface. A total of 17 adhesive/concentration/reactivation combinations were found to produce bonds evaluated as 'probably strong enough' to support top cover fabric within the context of the *Globe* with each of the four tested approaches, represented by Groups One – Four, producing at least one of the bonds. When these 17 bonds were further evaluated they revealed four combinations which also failed in the desired location without causing damage to fabric or foam. Again, each tested group in the round produced one of these combinations. The details behind each of these conclusions are presented below.

5.3.2.1 – Mass of adhesive applied

The average mass of liquid adhesive applied to samples is presented in Table 11 by adhesive type, adhesive concentration and application method. As one might expect, within each adhesive type and concentration, the average mass of liquid adhesive applied usually increased as the application method moved from one stroke, to two strokes to multiple strokes. Also, within each adhesive type and application method the average mass of liquid adhesive applied usually increased as the adhesive concentration increased. There are exceptions. With Isinglass 4% the average mass applied was just about equal for the two and multiple stroke application methods. With Plextol applied with the two stroke method the average mass applied was slightly less at 50% w/v than it was at 25% w/v. However, the general trend of an increase in mass with an increase in concentration or number of applied brush strokes is clear.

Table 11: The average mass of liquid adhesive applied to the samples in Round One, Groups One, Three and Four. The figures are presented by adhesive type, concentration and application technique.

Adhesive	**Concentration**	**Average mass in g/cm^2** (number of samples represented in average) (range if figure represented by more than one sample)		
		One Stroke	**Two Strokes**	**Multiple Strokes**
Impranil	50% w/v	0.012 (1)	0.021 (1)	0.033 (1)
	100%	0.044 (1)	0.064 (1)	0.084 (1)
Isinglass	4% w/v	0.015 (3) (0.013 - 0.017)	0.035 (3) (0.024 – 0.048)	0.034 (3) (0.030 0.039)
	10% w/v	0.022 (3) (0.020 – 0.023)	0.037 (3) (0.032 – 0.045)	0.050 (3) (0.040 – 0.057)
Lascaux	25% w/v	--	0.036 (3) (0.036 - 0.037)	--
	50% w/v	0.048 (1)	0.059 (4) (0.056 – 0.066)	0.060 (1)
	75% w/v	0.051 (1)	0.070 (4) (0.060 – 0.082)	0.093 (1)
Plextol	25% w/v	--	0.039 (3) (0.035 – 0.043)	
	50% w/v	--	0.035 (3) (0.033 – 0.039)	
	75% w/v	--	0.049 (3) (0.043 – 0.058)	
	100%	0.050 (4) (0.048 – 0.051)	0.067 (4) (0.059 – 0.073)	0.091 (4) (0.080 – 0.101)

5.3.2.2 – Adhesive drying time

The average drying time for each adhesive type, concentration and application method is are presented in Table 12. The data shows that when examined across comparable concentrations and application methods Impranil dries the fastest, Plextol next and Lascaux takes the longest amount of time to dry. For Impranil and Isinglass the drying time always increased with an increase in concentration when examined within a particular application method. The same can not be said of Lascaux or Plextol. Unsurprisingly, when examined within a particular adhesive type samples which represented the highest concentration applied with multiple brush strokes took the longest amount of time to dry. The adhesive which took the least amount of time to dry, 1 hour, was Impranil – 50% w/v applied with a single brush stroke. The adhesive which took the longest amount of time, just under 7 hours, was Lascaux – 75% w/v applied with multiple strokes.

Table 12: The average drying time of liquid adhesive applied to the samples in Round One, Groups One and Three. The figures are presented by adhesive type and concentration and application technique.

Adhesive	Concentration	Average time in hours (number of samples represented in average) (range if figure represented by more than one sample)		
		One Stroke	Two Strokes	Many Strokes
Impranil	50% w/v	1.00 (1)	1.17 (1)	2.17 (1)
	100%	2.08 (1)	2.08 (1)	5.17 (1)
Lascaux	25% w/v	--	2.55 (3) (2.30 – 2.75)	--
	50% w/v	2.88 (1)	3.92 (4) (3.42 – 4.17)	4.62 (1)
	75% w/v	2.88 (1)	3.83 (4) (3.23 – 4.08)	6.77 (1)
Plextol	25% w/v	--	2.67 (3) (2.50 – 2.83)	--
	50% w/v	--	2.22 (3) (1.72 – 2.75)	--
	75% w/v	--	2.08 (3) (2.08 – 2.08)	--
	100%	2.12 (1)	2.75 (1)	3.97 (1)

5.3.2.3 – Altered characteristics of the dry adhesive film coated samples

The results of the evaluations which considered changes in the foam samples due to the addition of an adhesive coating are summarized in Table 13. Overall the Beva and Impranil samples recovered most quickly from a momentary compression and at a rate equal to the recovery of an uncoated sample. The Lascaux samples took the longest time to recover with the Plextol samples usually taking a second or two less time to recover when compared to Lascaux at equal concentrations. Medium to heavy films were only produced with 100% concentrations of liquid adhesives and Beva - 65 μm with almost all other films being evaluated as light. Almost not detectable films were only produced with liquid adhesives at the lowest concentration – 25%. Beva always produced a continuous film. The film produced by the liquid adhesives usually became more continuous as the concentration increased however Lascaux presents exceptions to this trend. Only four samples had anything other than a soft flexible film. Those samples were Impranil – 100% applied with all three brush stroke patterns and Plextol – 100% applied with multiple strokes. The penetration of the film was even in all samples evaluated in Round One.

Table 13: A summary of the changes in the character of the foam samples in Round One, Groups One, Two and Three due to the addition of an adhesive coating. Section 5.2.2 gives details of categories and methods of evaluation.

Adhesive	**Application Method**	**Number of samples**	**Recovery time from momentary compression in seconds**	**Apparent adhesive film thickness**	**Continuity of adhesive film**	**Flexibility of adhesive film**	**Penetration of adhesive film**
Beva – 25 µm	T	9	Immediate	Light	Continuous	Soft	Even
Beva – 65 µm	T	9	Immediate	Medium	Continuous	Soft	Even
Impranil – 50% w/v	1	1	Immediate	Light	HPLC	Soft	Even
	2	1	Immediate	Light	HPLC	Soft	Even
	M	1	Immediate	Light	HPCS	Soft	Even
Impranil – 100%	1	1	Immediate	Medium	BCHCS	Stiff	Even
	2	1	Immediate	Medium	BCHCS	Stiff	Even
	M	1	Immediate	Heavy	BCHCS	Stiff	Even
Lascaux – 25% w/v	2	3	<1 – 2	AND	NATD	Soft	Even
Lascaux – 50% w/v	1	1	<1	Light	Continuous	Soft	Even
	2	4	1 – 5	Light	HPCS & BCHCS	Soft	Even
	M	1	1 – 2	Light	BCHCS	Soft	Even
Lascaux – 75% w/v	1	1	2 – 5	Light	BCHCS	Soft	Even
	2	4	2 – 5	Light	HPCS & Continuous	Soft	Even
	M	1	>5	Light	BCHCS	Soft	Even
Plextol – 25% w/v	2	3	Immediate	AND	NATD	Soft	Even
Plextol – 50% w/v	2	3	<1 – 2	Light	HPCS	Soft	Even
Plextol – 75% w/v	2	3	1 – 2	Light	HPCS	Soft	Even
Plextol – 100%	1	4	2 – 5	Medium	Continuous	Soft	Even
	2	4	1 – 2	Medium	BCHCS	Soft	Even
	M	4	1 - 2	Heavy	BCHCS	Stiff	Even
Control One	N/A	1	Immediate	No film	No film	Soft	No film
Control Two	S	1	Immediate	Medium	HPCS	Soft	Even

Legend:

Application method – ***1*** = one brush stroke; ***2*** = two brush strokes; ***M*** = multiple brush strokes; ***T*** = heat tacked; ***S*** = sprayed

Apparent adhesive film thickness – ***AND*** = almost not detectable

Continuity of adhesive film – ***BCHCS*** = basically continuous with holes generally the size of cells; ***HPCS*** = holes primarily cell sized with a few larger holes; ***HPLC*** = holes primarily larger than a cell with a few cell sized holes; ***NATD*** = not able to determine with the naked eye

See Table 6, Page 149 for more detailed information.

5.3.2.4 – Adhesive bond strength

With respect to apparent adhesive strength, all four tested approaches to the adhesion of fabric to foam produced some bonds evaluated as 'probably strong enough' (yellow highlights in Table 14). This meant that during a manual peel the bond appeared to be strong enough to support the top cover fabric within the context of the *Globe*. Group One identified Lascaux – 75% w/v reactivated at 90 °C for 180 seconds as apparently strong enough. Group Two determined that for all tested reactivation parameters other than 25 μm film tacked at 75 °C for 15 seconds Beva had produced bonds of at least apparently reasonable strength. Group Three, which tested the approach of consolidating the naturally aged adhesive with one liquid adhesive and then adhering fabric to that surface with Beva, achieved a 100% success rate with respect to producing 'probably strong enough' bonds. Group Four produced such bonds with Plextol – 100% and Isinglass – 10% w/v by utilizing the tacky stage in the drying process in two slightly different ways. In Groups One, Two and Four, the bonds not referred to above were all identified as clearly too weak (Table 14).

Table 14: The apparent bond strength of the samples produced for each experimental group evaluated in Stage One: Round One. Those samples evaluated as 'probably strong enough' are highlighted in yellow.

			Number of Samples Evaluated at Each Strength (Length of time reactivated in seconds or liquid adhesive application technique)			
Group	**Adhesive**	**Reactivation parameters which distinguish samples within an adhesive concentration**	**No Adhesion**	**Slight Adhesion**	**Stronger Adhesion**	**Probably Strong Enough**
One	Lascaux – 50% w/v				3	
	Lascaux – 75% w/v					3
	Plextol - 100%				3	
Two	Beva – 25 μm	75 °C tacked for 15s			3	
		75 °C tacked for 30s			1 (150)	2 (90, 120)
		85 °C tacked for 15s				3
	Beva – 65 μm	75 °C tacked for 15s			1 (90)	2 (120, 150)
		75 °C tacked for 30s				3
		85 °C tacked for 15s				3
Three	Lascaux – 25% w/v and Beva – 65 μm					3
	Lascaux – 50% w/v and Beva – 65 μm					3
	Lascaux – 75% w/v and Beva – 65 μm					3
	Plextol – 25% w/v and Beva – 65 μm					3
	Plextol – 50% w/v and Beva – 65 μm					3
	Plextol – 75% w/v and Beva – 65 μm					3
	Impranil – 50% w/v and Beva – 65 μm					3
	Impranil – 100% and Beva – 65 μm					3
Four	Isinglass – 4% w/v	Reactivate only		3		
		Weight and reactivate		2 (2, M)	1 (1)	
		Weight only		2 (1, 2)	1 (M)	
	Isinglass – 10% w/v	Reactivate only	1 (M)	2 (1, 2)		
		Weight and reactivate	1 (M)		1 (2)	1 (1)
		Weight only	1 (M)	2 (1, 2)		
	Plextol – 100%	Reactivate only				3
		Weight and reactivate			1 (1)	2 (2, M)
		Weight only		1	2	

Legend:

Application method – ***1*** = one brush stroke; ***2*** = two brush strokes; ***M*** = multiple brush strokes

5.3.2.5 – Damage caused to fabric and foam

When manually peeled apart, all bonds evaluated at a strength level of 'no adhesion', 'slight adhesion' or 'stronger adhesion' failed between the fabric and a consolidated foam surface or between Beva and an unconsolidated foam surface. In all cases no damage was caused to fabric or foam by the process.

The bonds which were evaluated at a strength level of 'probably strong enough' failed in a variety of locations causing different levels of damage as detailed in Table 15. Those which have been highlighted in pink failed in what was identified as the ideal location for each adhesion approach. These locations were identified as ideal because in each case such a failure had the greatest potential to protect fabric and foam. For those using only a liquid adhesive this location was between the fabric and the consolidated foam surface, the only location in which failure could take place without damaging the foam or fabric in the sample. For the combinations using Beva failure between the Beva and the foam surface, whether it was consolidated or not, was identified as ideal. This was so because it was assumed that if the Beva remained secured to the top cover fabric during bond failure it would protect the fabric during the process. Then the Beva could be removed from the fabric under controlled conditions at a later date. This ideal location for failure was also based on the requirement that as the Beva pulled away from the consolidated or unconsolidated foam surface no damage was done to the foam.

In Table 15, those rows which have a blue highlight as well as a pink one reveal samples where the location of failure was not only ideal but the process of peeling the bond apart caused no apparent damage to fabric or foam. There are four combinations which produced this result, one from each group, and it is these combinations which represent what was considered ideal – an apparently strong enough bond, which failed in the ideal location and caused no damage to fabric or foam in the process. Those four combinations were:

- Lascaux – 75% w/v - reactivated at 90 °C for 180 seconds
- Beva – 25 μm - tacked at 85 °C for 15 seconds and reactivated at 85 °C for 150 seconds
- Impranil – 100% and Beva – 65 μm - tacked at 85 °C for 15 seconds and reactivated at 85 °C for 90 seconds
- Isinglass – 10% w/v – upon reaching a tacky stage fabric weighted for 90 min and then reactivated at 80 °C for 90 seconds

Table 15: The location in which each 'probably strong enough' bond failed during a manual peel and the type of damage caused by the failure. Samples which failed in the ideal location have been highlighted in pink. Those which have also been highlighted in blue caused no apparent damage during the peeling process.

		Location of bond failure (length of reactivation time in seconds if result not consistent for all samples)			**Damage caused** (length of reactivation time in seconds if result not consistent for all samples)		
Group	**Adhesive and distinguishing reactivation parameters (number of samples)**	**Between fabric and Beva or consolidate foam**	**Between Beva and foam**	**Within the foam**	**None**	**Fabric**	**Foam**
One	Lascaux – 75% w/v (3)	X			X		
Two	Beva – 25 µm - 75 °C tacked for 30s (2)	X		X		X	X
	Beva – 25 µm - 85 °C tacked for 15s (3)		X (150)	X (90, 120)	X (150)	X (90, 120)	X (90, 120)
	Beva – 65 µm - 75 °C tacked for 15s (2)			X			X
	Beva – 65 µm - 75 °C tacked for 30s (3)	X		X		X	X
	Beva – 65 µm - 85 °C tacked for 15s (3)			X			X
Three	Lascaux – 25% w/v and Beva – 65 µm (3)		X				X
	Lascaux – 50% w/v and Beva – 65 µm (3)		X				X
	Lascaux – 75% w/v and Beva – 65 µm (3)		X				X
	Plextol – 25% w/v and Beva – 65 µm (3)	X (90)	X (120, 150)			X (90)	X (120, 150)
	Plextol – 50% w/v and Beva – 65 µm (3)		X				X
	Plextol – 75% w/v and Beva – 65 µm (3)	X (90)	X (120, 150)			X (90)	X (120, 150)
	Impranil – 50% w/v and Beva – 65 µm (3)		X				X
	Impranil – 100% and Beva – 65 µm (3)		X		X		
Four	Isinglass – 10% w/v - weight and reactivate (1)	X			X		
	Plextol – 100% - reactivate only (3)			X			X
	Plextol – 100% - weight and reactivate (2)			X			X

5.3.3 – Round One – the implications

With the process behind the data above, the primary goal of Round One, to find a way to bond 100% wool fabric to naturally aged polyether polyurethane foam using the identified conservation materials, had been met. 17 combinations had been found which produced bonds of a strength that appeared to be sufficient. Four of the combinations also appeared to offer solutions to what had been identified as the primary goal for Round Two – the next round of experimentation. That goal was to find a bond that was not only of an apparently reasonable strength but also caused little or no damage to fabric or foam when it was pulled apart. By more closely examining these four promising combinations, the overall results of the work used to test the specific approaches used to achieve them, and the other data collected in the process a detailed plan for Round Two was developed.

Once again, the four promising bonds which had been identified were produced as laid out in Table 16. As presented in Section 5.3.2.5, they all could be assumed to be equally viable. However, when examined in a larger context they are not. The Isinglass bond was produced by utilizing a tacky stage in the adhesive drying process and while the process produced this one successful bond the technique itself proved to be very uncontrollable and unpredictable. In several cases, although the adhesive was identified as being tacky it was still wet enough that when fabric was applied to it the adhesive penetrated into the fabric rather than achieving adhesion at the surface level. In another case (Isinglass – 10% w/v applied with multiple strokes) the tacky stage in the drying process had not been identified in Round One although it had in initial testing. Therefore, the technique of utilizing a tacky stage, and the Isinglass bond in Table 16, would be eliminated from further testing on the grounds that although in some cases it might produce a 'perfect' bond achieving that bond was not a controllable, predictable, generally repeatable process.

Table 16: The four combinations which achieved not only apparently reasonable bond strength in Round One but also failed in the desired location without causing damage to fabric or foam.

Adhesive	Application Method	Reactivation Method
Lascaux – 75% w/v	1, 2 & M	Immediately after Lascaux dried reactivated at 90 °C for 180 s
Beva – 25 μm	T - 85 °C for 15 s	Reactivated at 85 °C for 150 s
Impranil – 100% & Beva – 25 μm	1, 2 & M T - 85 °C for 15 s	Reactivated at 85 °C for 90 s
Isinglass – 10% w/v	1	Upon reaching a tacky stage fabric applied to the adhesive and weighted for 90 min and then reactivated at 80 °C for 90 s

Legend:

Application method – *1* = one brush stroke; *2* = two brush strokes; *M* = multiple brush strokes; *T* = tacked with heat

The Lascaux – 75% w/v combination in Table 16 represents the one apparently successful bond created with the use of a single liquid adhesive applied to foam and reactivated with heat. Initial testing had investigated this approach with eight adhesive/concentrations, three liquid adhesive application techniques and 26 reactivation temperature and time variations. Round One had further investigated the approach using combinations shown to be somewhat successful in initial testing with the additional variable that perhaps length of time between initial application and reactivation was significant. Through the entire process, only one apparently successful bond had been found. Without returning to the drawing board with respect to the selection of adhesives or application techniques the variations on this approach had been exhausted. Thus, although the Lascaux bond had met with success and it would be carried forward into Round Two for further testing, all other possibilities with respect to adhering fabric to foam with the heat reactivation of a single liquid adhesive would be eliminated.

This left the two combinations in Table 16 which involved the use of Beva. Without a doubt they showed the most promise with respect to adhering fabric to foam. Of the 42 samples in Round One which used Beva, 37 of them had been evaluated with a bond strength of 'probably strong enough'. However, only four of the 37 had also failed in an appropriate location without causing damage to fabric or foam. Therefore, the two approaches which used Beva would be the primary methods of adhesion carried forward into Round Two but experimentation would need to concentrate on finding a way to establish sufficient bond strength but induce failure in a location that did not damage fabric and/or foam.

This process would focus most of its efforts on the approach that used one liquid adhesive to consolidate the naturally aged foam surface and then used Beva to secure fabric to that consolidated surface. It would do so because the approach offered the most promise for creating the desired bond. It appeared to seal the foam surface separating and protecting it. In so doing it provided a stable strong surface to which to adhere the fabric with another adhesive. This in turn offered the possibility that bond failure could be engineered between the two adhesives rather than within the fabric or the foam.

It was hypothesized that what needed to happen is the bond between the Beva and the consolidated surface needed to be weakened. However care would need to be taken to only weaken the bond to a point where it was weaker than the foam or the Beva/fabric bond in the sample without being so weak that it would not support fabric within the context of the *Globe.* Attempts to weaken the bond would be carried out in three ways. The degraded polychloroprene adhesive coated surface of the foam would be used in testing rather than the uncoated foam surface as it was assumed that the presence of this rough degraded surface could change bond strength. A lower temperature than the 85 °C used in Round One, Group Three, for the tacking and reactivation of the Beva would be tried as the results of Group Two testing showed that a reduction in temperature generally weakened Beva bonds. Beva would be adhered to the consolidated surface immediately after that surface appeared dry and 24 hours after the liquid adhesive had been applied.[114]

In this way the Beva and consolidant approach to adhesion would become the primary focus of Round Two. However, the Beva only approach would also be considered. It was assumed that the addition of a degraded polychloroprene adhesive coated foam surface could weaken the Beva/unconsolidated foam bond in a way that would make the

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[114] The idea that the amount of time a liquid adhesive was left after initial application and before reactivation would make a difference in final bond strength was tested with Round One, Group One. No obvious difference in bond strength between adhesives reactivated as soon as they appeared dry and those reactivated 48 hours after application was identified. However, the number of samples used to test the hypothesis did not allow for conclusive results therefore it would be further tested as a potential way of reducing bond strength between Beva and a consolidated foam surface.

bond both of an apparently appropriate strength and quality. Therefore, this surface would be used to test Beva alone alongside Beva and a liquid adhesive. For the same reason, the addition of the degraded adhesive coated foam surface would also be used in testing the previously identified Lascaux bond.

Alongside which adhesion methods and adhesive combinations would be taken forward into Round Two the data from Round One also made it possible to determine that no adhesive was going to be eliminated from the testing process based on how it changed the character of the foam once applied. Perhaps, ideally conservation would in no way alter the *Globe*. However this was unachievable if the profile of the chair was to be restored. Therefore, each possible change needed to be considered from the perspective of total impact. It was accepted that a change in the rate of recovery from momentary compression, the thickness of the film, the flexibility of the film and the depth of penetration of the film might affect the feel of the chair if someone compressed the foam or sat in it but as this is not meant to be done with most museum objects this did not need to be a primary concern. The thickness of the film and the continuity had the potential to change the look of the surface of the foam but as the foam surface would eventually be covered with fabric it was again decided that any visual changes in surface characteristics did not need to be a primary concern. The adhesives did change the character of the foam samples but not in a way that was considered so significant that it outweighed the potential of the adhesive to produce the desired bond. Therefore, Impranil, Lascaux and Plextol could all be investigated with respect to consolidating the foam surface prior to the application of Beva film.

With this decision consideration was given to whether or not the evaluation of the conservation adhesive coated foam samples could cease. It had served its purpose with respect to determining whether or not the applied adhesives changed the nature of the foam in a way that should eliminate one, some or all of the adhesives from testing. However, the accumulated data was not yet of a sufficient quantity to allow even rough conclusions to be drawn with respect to how adhesive film quality might affect bond results, a second purpose of the evaluation. Similarly, the same could be said of the data related to the mass of liquid adhesive applied per square centimetre. Therefore, Round

Two would continue to monitor these details for the purpose of using them to consider how they do or do not affect bond results.[115]

5.3.4 – Round Two – the process

Replicates were added to the sample sets for Round Two. Most of the data to date had been collected from single samples which was appropriate for initial process development. However, Round Two, unlike initial testing or Round One, was trying to identify greater subtleties in the adhesion process. It was looking for adhesive/concentration/reactivation combinations which would produce *Globe* chair appropriate, reproducible bonds. Replicates which would show results to be consistent or inconsistent were needed. The number of replicates for each sample set was limited to three in order to work within the confines of the amount of available foam, validate test results to a certain standard and test the adhesive/concentration/reactivation combinations Round One had identified as worthy of further consideration.

The primary thing to determine with each sample set was no longer whether a bond could be established as it had been determined that all the included combinations definitely secured fabric to foam. It was whether or not the bond each adhesive combination produced was of an apparently reasonable strength. Apparently reasonable was defined by the fact that when the fabric was pulled from the foam there was no obvious damage done to the foam or fabric while subjectively the bond felt strong enough that it would be able to support the *Globe* chair's top cover fabric over years rather than weeks or months.

Three distinct sets of samples were designed to test the three approaches to adhesion Round One had identified as still viable with respect to achieving this apparently reasonable bond. For each set 5.0 cm x 4.0 cm x 4.0 cm blocks of foam and 6.0 cm x 4.0 cm pieces of surrogate fabric were cut. This time the foam surface which would be used for testing was the 5.0 cm x 4.0 cm surface which included the degraded polychloroprene based adhesive originally used to secure the top cover to obverse

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[115] Beva was eliminated from the film quality monitoring process as the qualities both the 25 μm and 65 μm films produced were 100% consistent – no doubt a result of the consistency of the film due to the process used to manufacture it.

surface of the foam. It would be used as it had been identified as one of the variables which might alter the previously tested bonds in a desired way. Additionally, at this stage of the testing process any experimentation which did not take into account the possibly significant variable of the degraded adhesive was not likely to produce results with the desired level of specificity. In preparing sets of replicates, no foam or fabric sample came from the same row or column or an immediately adjacent location from which it was cut out of the original sample material. For each sample which was to be coated with liquid adhesive, one length and one width measurement of the foam surface to which the adhesive would be applied was taken. Then each sample was weighed before and immediately after liquid adhesive application which was carried out using the two stroke technique.[116] For those samples which would be reactivated as soon as the sample appeared dry, the drying process was observed and when the adhesive appeared to be dry the time it took to achieve this state was recorded. Just prior to reactivation all samples to which liquid adhesive had been applied were evaluated using the criteria described in Section 5.2.2. Reactivation was then carried out in a variety of ways, as described below. Once each reactivation process was complete the samples were left overnight. The following morning the fabric was manually peeled from the foam and the results were recorded as set out in Section 5.2.4.

Group One - This set of samples was prepared with the primary goal of determining whether or not a polyether polyurethane foam surface coated in degraded polychloroprene could be consolidated using one of the liquid adhesives being tested and then have fabric adhered to the adhesive coated surface using Beva, resulting in a bond of apparently reasonable strength and quality. For this set several other variables beyond what has been described above define its parameters. First, the liquid adhesive which would be tested would be Impranil, Lascaux and Plextol and three concentrations of each would be used. As all concentrations used in Round One had produced bonds which were 'probably strong enough' they would be used again with the addition of Impranil – 75% w/v.[117] For the same reason, Beva – 65 µm would be used as it was in Round One. This would allow for direct comparison of samples across rounds where the only variable was the presence or absence of the degraded polychloroprene based

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[116] The two stroke technique had been used to produce all of the samples in Round One which were carried forward into Round Two. It was obviously one piece in the puzzle that was providing promising results. It was therefore considered ideal to carry it forward for use in Round Two.

[117] Only two concentrations of Impranil had been used in Round One, 50% w/v and 100%.

adhesive coated surface. Second, two different temperatures and one time parameter would be used to tack and reactivate the Beva. One would be 85 °C for a 15 second tack and a 90 second reactivation. This parameter was the one that produced the 'ideal' bond with Beva and Impranil – 100% in Round One and in all other cases bonds that were 'probably strong enough' but also caused damaged to fabric or foam. The other would be 75 °C for a 15 second tack and a 90 second reactivation. This parameter had produced a bond that was too weak in Round One when Beva was used on its own. Additionally, Round Two had also shown that a reduction in reactivation temperature generally resulted in a reduced Beva bond strength and one of the goals of Round Two was to reduce the Beva bond strength produced by the 85 °C parameter. The final variable was the continuation of experiments designed to examine whether the length of adhesive curing time before reactivation had an effect on bond strength. Sample sets with the same adhesive concentration would have identical application and reactivation procedures carried out but in one set the reactivation would take place as soon as the liquid adhesive appeared dry and the other would take place approximately 24 hours after liquid adhesive application.

The samples were prepared as detailed in Table 17. Reactivation was carried out by tacking a sample of Beva to the entire adhesive covered surface and leaving it to cool for at least 5 minutes. Then fabric was placed on the Beva and the sample was reactivated.

Table 17: The samples prepared for Round Two, Group One.

Sample #	Adhesive Type	Concentration	Drying/Curing Time	Reactivation Temp
600-602	Lascaux	25% w/v	24 hours	75 °C
603-605				85 °C
606-608			To apparent dryness	75 °C
609-611				85 °C
612-614		50% w/v	24 hours	75 °C
615-617				85 °C
618-620			To apparent dryness	75 °C
621-623				85 °C
624-626		75% w/v	24 hours	75 °C
627-629				85 °C
630-632			To apparent dryness	75 °C
633-635				85 °C
636-638	Plextol	25% w/v	24 hours	75 °C
639-641				85 °C
642-644			To apparent dryness	75 °C
645-647				85 °C
648-650		50% w/v	24 hours	75 °C
651-653				85 °C
654-656			To apparent dryness	75 °C
657-659				85 °C
660-662		75% w/v	24 hours	75 °C
663-665				85 °C
666-668			To apparent dryness	75 °C
669-671				85 °C
672-674	Impranil	50% w/v	24 hours	75 °C
675-677				85 °C
678-680			To apparent dryness	75 °C
681-683				85 °C
684-686		75% w/v	24 hours	75 °C
687-689				85 °C
690-692			To apparent dryness	75 °C
693-695				85 °C
696-698		100%	24 hours	75 °C
699-701				85 °C
702-704			To apparent dryness	75 °C
705-707				85 °C

Legend:

Drying/Curing Time – ***24 hours*** = application of Beva and fabric took place approximately 24 hours after the liquid adhesive was originally applied; ***To apparent dryness*** = application of Beva and fabric took place as soon as the applied liquid adhesive reached apparent dryness

Group Two - This sample set was prepared with the primary goal of determining whether Beva – 25 μm or 65 μm and the tacking and reactivation times and temperatures used for Group One produced an appropriate bond between wool fabric and naturally degraded polychloroprene based adhesive coated polyether polyurethane foam. While Beva alone had so far only produced one 'ideal' bond and in all other cases consistently produced bonds which were either too weak or apparently strong enough but damage causing, this set would determine whether or not the introduction of the degraded polychloroprene based adhesive changed those results. Each prepared foam sample had Beva tacked to its surface for 15 seconds and was then left to cool for at least 5 minutes. Then fabric was placed on the sample and it was reactivated for 90 seconds at the temperatures detailed in Table 18.

Table 18: The samples prepared for Round Two, Group Two.

Sample #	Adhesive	Tacking and Reactivation Temperature
708 - 710	Beva – 25 μm	75°c
711 - 713		85°c
714 - 716	Beva – 65 μm	75°c
717 - 719		85°c

Group Three - This final set of samples for Round Two was prepared in order to test whether the one apparently viable Lascaux only solution continued to appear to be apparently successful once the degraded polychloroprene based adhesive surface was added to the testing parameters. The samples were prepared as detailed in Table 19 with reactivation taking place as soon as the identified drying/curing time had been reached.

Table 19: The samples prepared for Round Two, Group Three.

Sample #	Adhesive	Concentration	Drying/Curing Time	Reactivation
720 - 722	Lascaux	75% w/v	24 hours	90°c for 180 seconds
723 - 725			To apparent dryness	

Legend:

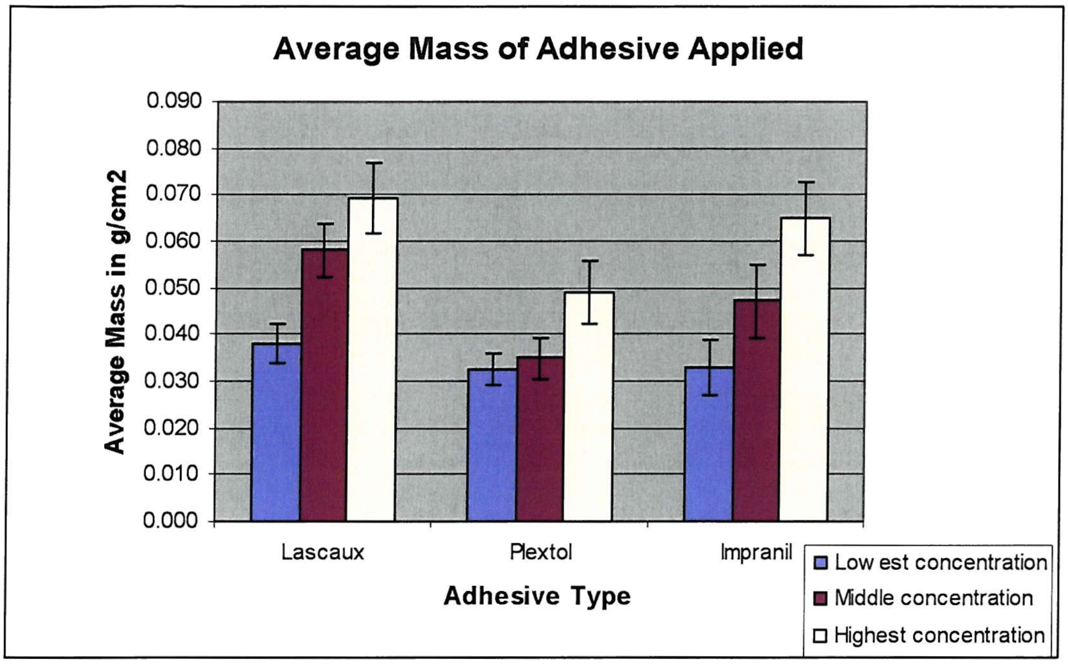
Drying/Curing Time – ***24 hours*** = application of Beva and fabric took place approximately 24 hours after the liquid adhesive was originally applied; ***To apparent dryness*** = application of Beva and fabric took place as soon as the applied liquid adhesive reached apparent dryness

5.3.5 – Round Two – the results

Overall, the testing revealed the following results. The average mass of liquid adhesive applied was consistent with the results of Round One. When considered alongside the bond strength and bond quality results some tentative evidence was found that a dependent relationship between this factor and bond strength existed. All liquid adhesives/concentrations were found to dry quickly enough to work within potential reactivation parameters regarding drying/curing time. No evaluated characteristic of the adhesive coated foam samples was determined to have a direct, definite effect on bond strength or quality. All adhesive/concentration/reactivation combinations tested in Round Two produced bonds which appeared to be strong enough to support top cover fabric in the context of the *Globe*. Of the 42 combinations tested 17 appeared to be not only strong enough but of a quality that caused no damage to fabric or foam as the bond failed. The details behind each of these conclusions are presented below.

5.3.5.1 – Mass of adhesive applied

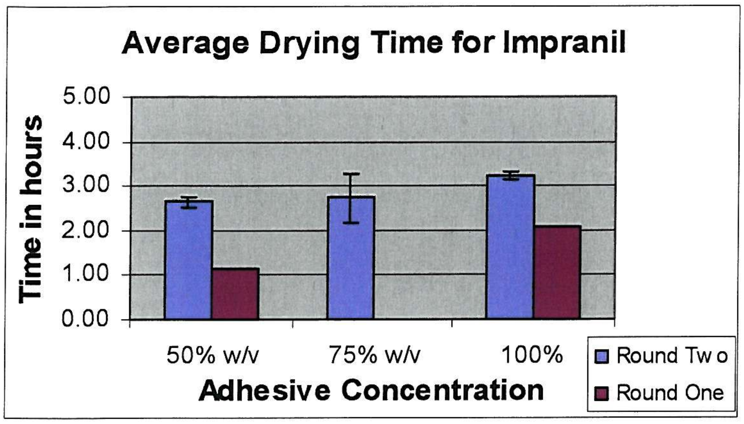
The primary reason for recording the mass of adhesive applied in this round was to consider whether it had any effect on bond results. This possibility is discussed following the presentation of bond results below (Section 5.3.5.6). The accumulated data is presented by adhesive type and concentration in Figure 98. As with Round One, within each adhesive type the average mass applied increased with concentration. The increase takes place in the most regular increments for Impranil and slightly less regular increments for Lascaux. With Plextol there is a curious anomaly which correlates with what was found in Round One. In Round One the average mass of adhesive applied actually dropped slightly when progressing from 25% w/v to 50% w/v. In Round Two the average mass did increase but only by a very small amount. A review of the data from both rounds leaves it completely unclear why this is the case.



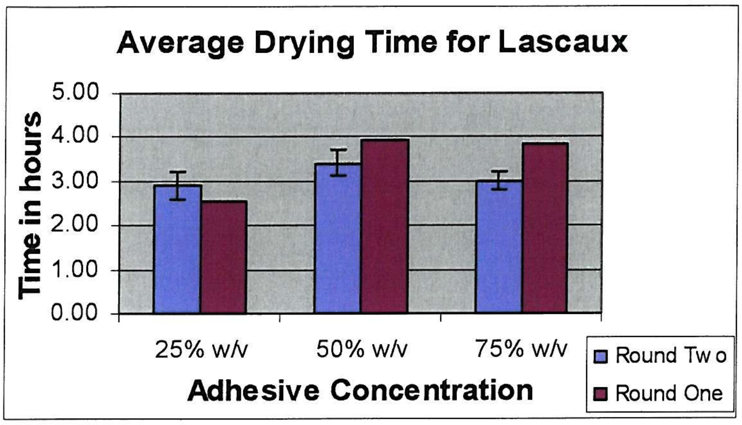
▲ Figure 98: The average mass of adhesive applied to samples, analyzed by adhesive type and concentration. Each average is represented by 12 samples.

5.3.5.2 – Adhesive drying time

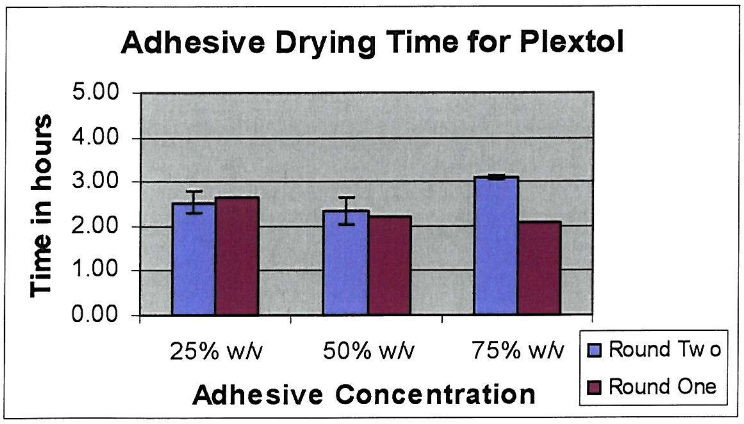
The drying times for each adhesive are presented in Figures 99 - 101 alongside the drying time for the equivalent adhesive and concentration applied with the two stroke method in Round One. The trends with respect to adhesive drying time and concentration were the same for Impranil and Lascaux when the results from Round One and Round Two were compared. The drying time for Impranil always increased with an increase in concentration. For Lascaux the drying time from longest to shortest was always 50% w/v > 75% w/v > 25% w/v. The drying time trends for Plextol were quite different in the two rounds. A comparison of drying time versus average mass of adhesive applied for each sample did not reveal any relationship which explained the variation in the drying times. It is assumed the variations in data are related to a variety of factors including mass of adhesive applied, ratio of water to solids content in each solution, and laboratory conditions on the day of application. However, for this work what is probably most significant is that no adhesive took longer than four hours to dry. This length of time would make it possible to apply an adhesive, let it dry and then immediately reactivate it all in one day if length of drying/curing time proved to be significant with respect to bond strength and quality.



▲ **Figure 99: The average drying time for Impranil applied with the two stroke method in both Rounds One and Two. The Round Two figures represent an average of six samples. The Round One figures represent only one sample with no 75% w/v sample produced in Round One.**



▲ **Figure 100: The average drying time for Lascaux applied with the two stroke method in both Rounds One and Two. The Round Two figures represent an average of six samples. The Round One figures represent an average of four or less samples as detailed with data ranges in Table 12, Page 160.**



▲ **Figure 101: The average drying time for Plextol applied with the two stroke method in both Rounds One and Two. The Round Two figures represent an average of six samples. The Round One figures represent an average of three samples with data ranges detailed in Table 12, Page 160.**

5.3.5.3 – Altered characteristics of the dry adhesive film coated samples

As with the mass of adhesive applied, the primary reason for recording the details of changes in characteristics of the foam samples following adhesive application in this round was to consider whether adhesive film characteristics had any affect on bond results. No such relationship was shown to exist. This conclusion was drawn with the accumulated data summarized in Table 20 in combination with the bond results presented below (Section 5.3.5.5).

Table 20: A summary of the changes in the character of the foam samples in Round One, Groups One and Three due to the addition of an adhesive coating. Section 5.2.2 gives details of categories and methods of evaluation.

Adhesive	**Number of samples**	**Recovery time from momentary compression in seconds**	**Apparent adhesive film thickness**	**Continuity of adhesive film**	**Flexibility of adhesive film**	**Penetration of adhesive film**
Impranil – 50% w/v	12	Immediate	Light	HPCS	Soft	Even
Impranil – 75% w/v	12	Immediate	Light	HPCS	Soft	Even
Impranil – 100%	12	Immediate	Medium	Continuous (2) BCHCS (10)	Soft	Even
Lascaux – 25% w/v	12	1 – >5	Light	NATD (6) HPCS (6)	Soft	Even
Lascaux – 50% w/v	12	1 – 5	Light	HPCS	Soft	Even
Lascaux – 75% w/v	18	1 – >5	Medium	Continuous (14) BCHCS (4)	Soft	Even
Plextol – 25% w/v	12	1 – 5	Light	NATD	Soft	Even
Plextol – 50% w/v	6	1 – 2	Light	HPCS	Soft	Even
Plextol – 75% w/v	12	2 – 5	Medium	BCHCS	Soft	Even
Control One	1	Immediate	No film	No film	Soft	No film
Control Two	1	Immediate	Medium	HPCS	Soft	Even

Legend:

Continuity of adhesive film – ***BCHCS*** = basically continuous with holes generally the size of cells; ***HPCS*** = holes primarily cell sized with a few larger holes; ***NATD*** = not able to determine with the naked eye

See Table 6, Page 149 for more detailed information.

5.3.5.4 – Adhesive bond strength

There were 126 samples, representing 42 adhesive/concentration/reactivation combinations, produced in Round Two. These samples were used to test three different methods for adhering 100% wool fabric to degraded polychloroprene based adhesive coated polyether polyurethane foam. Twenty-four hours after fabric was adhered to foam in each sample the fabric was manually peeled from the foam surface. In all 126 samples the strength of the bond was evaluated as ‘probably strong enough’ to adhere fabric to foam in the context of the *Globe*.

5.3.5.5 – Damage caused to fabric or foam

The 126 samples were then examined to determine if the peeling process had caused damage to fabric and/or foam. If any damage in any of the three samples in a replicate set was noted the combination was eliminated from further consideration. Damage could be anything more than a few individual fibres being removed from the fabric by the adhesive coated surface as the fabric was peeled away. It could be anything more than a few pin tip size pieces of consolidated foam being removed from the foam surface by the fabric as it was peeled away. It could be the entire consolidated surface of the foam being pulled away with the fabric. The result of the evaluation was that 25 of the original 42 adhesive/concentration/reactivation combinations were eliminated: all of the Beva only combinations; one of the two Lascaux only combinations; a variety of Beva and consolidant combinations which represented each liquid adhesive tested at all but one concentration (Table 21). This left 17 combinations which appeared to produce bonds of apparently appropriate strength and appeared to do no damage to fabric or foam when manually peeled apart. The combinations included one Lascaux only solution, Lascaux & Beva and Plextol & Beva at all three tested concentrations reactivated at 75 ^{o}C and Impranil & Beva reactivated at 75 ^{o}C or 85 ^{o}C depending on concentration and drying/curing time.

Table 21: The adhesive/concentration/reactivation combinations which were eliminated from further consideration because the peeling process caused damage to fabric or foam.

Adhesive	**Drying/Curing Time**	**Reactivation Temperature**	**Damage Caused**	
			Fabric	**Foam**
Beva – 25 µm	n/a	85 °C		X
		75 °C		X
Beva – 65 µm	n/a	85 °C		X
		75 °C		X
Impranil – 50% & Beva – 65 µm	24 hours	85 °C		X
	To apparent dryness	75 °C	X	X
		85 °C	X	X
Impranil – 75% & Beva – 65 µm	24 hours	85 °C	X	X
Lascaux – 25% & Beva – 65 µm	24 hours	85 °C		X
		75 °C		X
	To apparent dryness	85 °C		X
Lascaux – 50% & Beva – 65 µm	24 hours	85 °C		X
	To apparent dryness	85 °C		X
		75 °C		X
Lascaux – 75% & Beva – 65 µm	24 hours	85 °C		X
	To apparent dryness	85 °C		X
		75 °C		X
Lascaux – 75%	24 hours	90 °C		X
Plextol – 25% & Beva – 65 µm	24 hours	85 °C		X
	To apparent dryness	85 °C		X
		75 °C		X
Plextol – 50% & Beva – 65 µm	24 hours	85 °C	X	X
	To apparent dryness	85 °C		X
Plextol – 75% & Beva – 65 µm	24 hours	85 °C		X
	To apparent dryness	85 °C	X	X

Legend:

Drying/Curing Time – ***24 hours*** = application of Beva and fabric took place approximately 24 hours after the liquid adhesive was originally applied; ***To apparent dryness*** = application of Beva and fabric took place as soon as the applied liquid adhesive reached apparent dryness

5.3.5.6 – Relationships between bond strength and other accumulated data

There is some very tentative evidence that a relationship between the mass of applied adhesive and bond strength/quality exists. There were nine replicate sets where only some of the samples were damaged by the peeling process rather than all or none. In six of these nine sets the sample or samples which were damaged showed a higher mass of applied adhesive per square centimetre than the undamaged one. There also seemed to be some possible correlations between bond strength/quality and drying/curing time. What these possible correlations were was less clear than with mass of applied adhesive but the possibility did suggest that the amount of drying/curing time should not be ignored in the bonding process. No other even tentative relationship between bond strength and accumulated data was found.

5.3.5 – Round Two – the implications

With the process behind the data above, the primary goal of Round Two, to find a bond which felt subjectively strong enough to support the *Globe's* top cover fabric and failed without causing obvious damage to fabric or foam, had been met. In fact 17 such bonds had been found (Table 22). However, all 17 could not be carried forward into Stage Two as the amount of remaining test material could only support taking a maximum of four combinations forward. Therefore a process was carried out to reduce 17 apparently successful solutions to four which would be used further experimentation.

Table 22: The 17 adhesive/concentration/reactivation combinations which appeared to be apparently viable at the conclusion of Round Two and the notes taken during the manual peel process which assisted in determining which combinations should be taken forward into Stage Two. The combinations which clearly caused no damage during the manual peel in all three replicates have been highlighted in green.

Adhesive	**Drying/Curing Time**	**Reactivation Temperature**	**Manual Peel Notes** **(number of samples represented by the note if not all three in the replicate set)**
Lascaux – 25% & Beva – 65 µm	To apparent dryness	75 °C	No visible damage
Lascaux – 50% & Beva – 65 µm	24 hours	75 °C	No visible damage
Lascaux – 75% & Beva – 65 µm	24 hours	75 °C	No visible damage
Plextol – 25% & Beva – 65 µm	24 hours	75 °C	No visible damage
Plextol – 50% & Beva – 65 µm	24 hours	75 °C	No visible damage
Plextol – 50% & Beva – 65 µm	To apparent dryness	75 °C	No visible damage
Plextol – 75% & Beva – 65 µm	24 hours	75 °C	No visible damage
Plextol – 75% & Beva – 65 µm	To apparent dryness	75 °C	No visible damage
Impranil – 50% & Beva – 65 µm	24 hours	75 °C	No visible damage
Impranil – 75% & Beva – 65 µm	24 hours	75 °C	No visible damage
Impranil – 75% & Beva – 65 µm	To apparent dryness	75 °C	No visible damage
Impranil – 75% & Beva – 65 µm		85 °C	Definitely no damage
Impranil – 100% & Beva – 65 µm	24 hours	75 °C	No visible damage (2) Definitely no damage (1)
Impranil – 100% & Beva – 65 µm		85 °C	Minute specks (1) Definitely no damage (2)
Impranil – 100% & Beva – 65 µm	To apparent dryness	75 °C	No visible damage (2) Definitely no damage (1)
Impranil – 100% & Beva – 65 µm		85 °C	Minute specks (1) Definitely no damage (2)
Lascaux – 75%	To apparent dryness	90 °C	Definitely no damage

Legend:

Drying/Curing Time – ***24 hours*** = application of Beva and fabric took place approximately 24 hours after the liquid adhesive was originally applied; ***To apparent dryness*** = application of Beva and fabric took place as soon as the applied liquid adhesive reached apparent dryness

Manual Peel Notes – ***Definitely no damage*** = The damage evaluation had revealed no damage to fabric or foam and there was no indication there might be hidden damage beneath the consolidated surface; ***Minute specks*** = Damage evaluation had revealed a few pin tip size pieces of foam or degraded adhesive stuck to the Beva as it pulled away from the foam surface. The pieces were small enough they were considered insignificant but the sample could not be qualified as having received no damage; ***No visible damage*** = Although the damage evaluation revealed no visible damage, the pull on the consolidated surface during the manual peel left the impression that it could damaging the foam beneath the centre of the consolidated surface.

A review of notes written during the evaluation of the damage caused by the manual peel process revealed that there were two combinations where all three replicates had been recorded as ***definitely*** doing no damage to foam or fabric (Table 22). In other sets of replicates one or two were noted as ***definitely*** doing no damage while the remaining samples left the possibility of damage open or removed minute specks of foam/degraded adhesive in the pulling process. The two combinations which were identified as ***definitely*** doing no damage in all three samples were:

- Impranil - 75% w/v & Beva - 65 μm with the Beva and fabric applied immediately after the Impranil had dried using a tacking and reactivation temperature of 85 °C
- Lascaux - 75% w/v with fabric applied immediately after the Lascaux had dried through reactivation of the Lascaux at a temperature of 90 °C

Combined with the following additional reasons these two combinations were selected as definitely worthy of further experimentation. The Impranil and Beva samples reactivated at a temperature of 85 °C not only caused no damage during the manual peel process they also failed between the consolidated foam surface and the Beva which was previously identified as the ideal location of failure. The Lascaux only set was the only combination which could be carried forward that did not include Beva and continued investigation of such a possibility was considered a positive option as it might offer a solution for an object and/or a situation where Beva was considered inappropriate.

Reasons for selecting two more combinations from the remaining 15 were less clear. However, in the end, it was noted that there were Lascaux - 75% w/v and Plextol - 75% w/v combinations which included Beva which were still being considered. Barring no other reason it was determined that by selecting these combinations there would be consistency with respect to concentration across all four combinations carried forward for further testing. The reactivation parameters for each combination would be selected based on what had proved most successful in each set during Round Two so that in the end the adhesive type would be the primary variable. If the results did not suggest that reactivation should happen immediately after the consolidating adhesive reached apparent dryness the reactivation would be carried out approximately 24 hours after liquid adhesive application as it was considered more practical for conservators. Thus the following four adhesive combinations were selected for Stage Two of testing:

- Impranil – 75% w/v brushed onto aged foam using the two stroke method; immediately after achieving apparent dryness Beva – 65 µm tacked to the adhesive coated surface at 85 °C for 15 seconds and then fabric adhered to the film at 85 °C for 90 seconds
- Lascaux – 75% w/v brushed onto aged foam using the two stroke method; 24 hours after liquid adhesive application Beva – 65 µm tacked to the adhesive coated surface at 75 °C for 15 seconds and then fabric adhered to the film at 75 °C for 90 seconds
- Plextol – 75% w/v brushed onto aged foam using the two stroke method; 24 hours after liquid adhesive application Beva – 65 µm tacked to the adhesive coated surface at 75 °C for 15 seconds and then fabric adhered to the film at 75 °C for 90 seconds
- Lascaux – 75% w/v brushed onto aged foam using the two stroke method; immediately after achieving apparent dryness fabric adhered to the adhesive coated surface at 90 °C for 180 seconds

When carrying these combinations forward the mass of adhesive applied would continue to be monitored in order to further consider the tentative evidence that mass of applied adhesive per square centimetre has an effect of bond strength/quality. It would also be monitored to assist with the analysis of a potentially significant detail which had revealed itself during Stage One: Round Two. That detail was the fact that as applied liquid adhesives dried they caused the foam surface to contract. It seemed possible that a good bond could be established using a particular adhesive but if that adhesive distorted the foam surface too much during the drying process it might not present a viable solution for the *Globe*. One of the primary goals for the conservation of the *Globe* was to restore the profile of the chair. If the adhesive used to re-secure top cover fabric to foam altered the profile of the foam due to surface contraction during the drying process the appropriate profile might not be able to be achieved.

5.4 - Conclusion

This brought Stage One of testing to a close. The stage had determined that brushing is an appropriate method of adhesive application in this situation and a two stroke method produced an appropriate adhesive film across adhesive types and concentrations. It determined that none of the evaluated characteristics of the dry adhesive films produced in the testing process suggested an adhesive should be eliminated from further testing on their account. However, it identified the surface shrinkage caused by the applied adhesive films as a characteristic which had the potential to identify an otherwise promising adhesive as inappropriate and therefore this characteristic would be monitored during Stage Two. It had determined that while adhering the two surfaces without heat or solvents had been the preferred method and utilizing a tacky stage in the drying process had been targeted as the means to this end the technique proved to be very unpredictable and uncontrollable which eliminated it from the testing process. It had determined that when using heat for reactivation Lascaux and Beva were the only adhesives tested which managed to bond fabric to foam on their own. One concentration of Lascaux was found to produce a bond of apparently reasonable strength which did no damage to foam or fabric when pulled apart. No combination of Beva film thickness and reactivation parameters was found to do this. The successful Lascaux combination was identified for further testing and the process of using Beva on its own was abandoned. The process of consolidating the foam surface with one adhesive and then adhering fabric to that surface with Beva was identified as the most promising solution for re-adhering the original fabric to the original foam in the *Globe* with 16 possible combinations appearing to produce bonds of reasonable strength while not damaging fabric or foam when peeled apart. Stage One had determined that it was possible to re-adhere the original fabric to the original foam in the *Globe* in an apparently conservation appropriate way.

Chapter 6 – Experimental Stage Two: Quantifiable Bond Strength and Longevity

Having established that an apparently successful bond between the test foam and test fabric could be produced in several different ways a second stage of experimentation was carried out. This stage sought to determine whether or not any of the four apparently successful bonds selected for further testing were of a quantifiable strength and quality appropriate for the conservation of the Globe. It identified one bond as likely to be of an appropriate strength and considered how long it was likely to remain viable if applied during the conservation of the Globe.

6.1 – Introduction

The first stage of experimentation set out to find answers to basic questions. If liquid adhesive was applied with a brush to naturally aged polyether polyurethane foam would acceptable results be achieved? Could Beva, Impranil, Isinglass, Lascaux and/or Plextol be used to create an apparently successful bond between degraded polychloroprene based adhesive coated polyether polyurethane foam and 100% wool fabric? Was reactivation of the tested adhesives going to be necessary in order to create a bond? In the process of carrying out work to answer these basic questions 17 apparently successful methods for re-adhering the two surfaces had been identified. Four of the 17 were then selected for further testing in Stage Two (Table 23). The final outcome of this stage was expected to be either the identification of at least one combination as worthy of use in the conservation of the *Globe* or the elimination of all four of these combinations from the list of apparently viable conservation solutions. The work to make this determination was carried out in two rounds of testing as described in detail in the following pages.

Table 23: The four adhesive/concentration/reactivation combinations carried forward into Stage Two for testing.

Adhesive	**Drying/Curing Time**	**Reactivation Parameters**
Lascaux – 75% w/v	To apparent dryness	90 °C for 180 seconds
Lascaux – 75% w/v & Beva – 65 μm	24 hours	75 °C for 15 second tack and 90 second reactivation
Impranil – 75% w/v & Beva – 65 μm	To apparent dryness	85 °C for 15 second tack and 90 second reactivation
Plextol – 75% w/v & Beva – 65 μm	24 hours	75 °C for 15 second tack and 90 second reactivation

6.2 – Methods of Testing and Evaluation

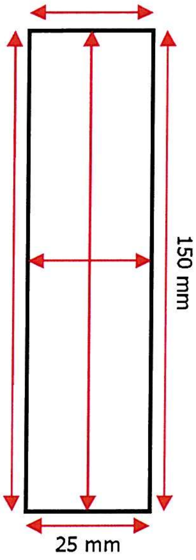
The general approach to the experimentation carried out in Stage Two would be to prepare sets of foam/adhesive/fabric samples. Half of each adhesive set would be tested to evaluate the bond. The other half would be subjected to a period of accelerated ageing and then subjected to the same tests which had been used for the first half of the adhesive set.

The analysis required for this stage would employ quantitative methods rather than the qualitative methods which had largely satisfied the needs of Stage One. The results of these methods would be used to determine whether each potential solution continued to appear to be viable. In this case, a viable solution would be one that showed signs of being neither too weak nor too strong when initially established. It would continue to adhere the two surfaces in question after a period of accelerated ageing while not becoming too weak or too strong. It would not distort the surface of the foam in a way that could not be accommodated in the conservation of the *Globe*.

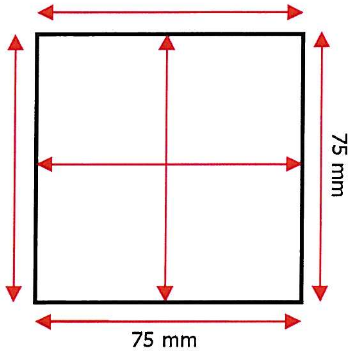
In order to provide the data necessary to make these determinations regarding viability, the testing needed to monitor the dimensional changes in the surface of the foam to which liquid adhesives were applied. It needed to quantify the strength, durability and longevity of the bonds produced. It needed to record where the established bonds failed during strength and durability testing and it needed to quantify the amount of damage done to both fabric and foam during the failure.

6.2.1 – Monitoring dimensional changes on the foam surface

Three length and three width measurements of each foam sample were taken prior to liquid adhesive application (Figures 102 & 103). These same measurements were then taken just prior to reactivation, after the adhesive had dried/cured for the optimum amount of time, as identified in Stage One. The measurements were recorded to the nearest 0.5 mm. The mass of each sample was also recorded before and immediately after liquid adhesive application.



▲ Figure 102: Measurements recorded for each peel test (Section 6.2.2.1) sample indicated by the red lines. Figures given in mm are the dimensions to which the sample was originally cut.



▲ Figure 103: Measurements recorded for each stress rupture test (Section 6.2.2.2) sample indicated by the red lines. Figures given in mm are the dimensions to which the sample was originally cut.

6.2.2 – Quantifying bond strength and durability

Bond strength and durability tests which measure the force or energy needed to break a joint are commonly used in the field of adhesion science to gather data to predict joint performance, select an adhesive from a group for a specific application and evaluate the effect of ageing. These three functions were defined goals for Stage Two. If these tests were executed with care taken to standardize sample size and test procedures the resulting data could provide strong comparative information within and across sample sets (Comyn 1997; Packham 2005). They had previously been used for such purposes in the field of conservation research. Karsten discusses their use with respect to the adhesive bonding of textiles (Karsten & Down 2005; Karsten & Kerr 2003; Karsten et al 2002). Berger and Zeliger (1984) discuss their use in evaluating adhesives for the lining of paintings. Therefore, they were identified as appropriate methods for quantifying adhesive bond strength and durability in this stage of testing.

Four tests were identified as tests which would evaluate stresses present in the *Globe*: shear, pull, peel and creep. Each would apply force to a sample in a slightly different way until the bond failed and in so doing quantify the strength and durability of the given bond. Peel tests and creep tests were additionally identified as tests which could also be performed on samples with flexible adherends and thus confirmed these two tests as appropriate choices for quantification of bond strength and durability in Stage Two. A peel test would apply increasing force to a sample until bond failure was initiated at one end. It would then apply a variable force that was just enough to pull the two adherends of the sample apart. This variable force would be continuously applied at a constant rate until the two adherends were completely separated. A creep test would apply a constant force at the centre of a sample and wait for failure to take place (Comyn 1997; Packham 2005; Shields 1984).[118] Each of these tests can be carried out in a variety of ways, thus a specific method for each meeting the specific needs of the planned experimentation needed to be designed. Those designs are summarized below.

6.2.2.1 – Peel tests

<u>Sample preparation</u> - Samples were prepared for this test by cutting 25 mm x 150 mm x 40 mm blocks of foam. 35 mm x 160 mm pieces of fabric were also cut and then unravelled along warp and weft to leave a 25 mm x 150 mm woven portion of each sample.[119] The necessary adhesives were applied to the entire 25 mm x 150 mm surface of the foam. Then fabric was adhered to the adhesive covered surface leaving 25 mm of one end unadhered.

<u>Testing process[120]</u> - One day prior to testing, the prepared samples were secured to aluminium mounts using Bostik All Purpose Extra Strong Clear Adhesive. At the start of a test the lower tongue of the mount was gripped in the lower clamp of an Instron 5544 operated with Bluehill™ software version 1.4. A thin metal plate with a hinge on its lower end was gripped by the upper clamp and the 25 mm fabric tail was secured in the hinge using two wing nuts to compress the hinge (Figure 104). With the sample mounted in place the Instron was then used to peel the fabric from the foam at an angle

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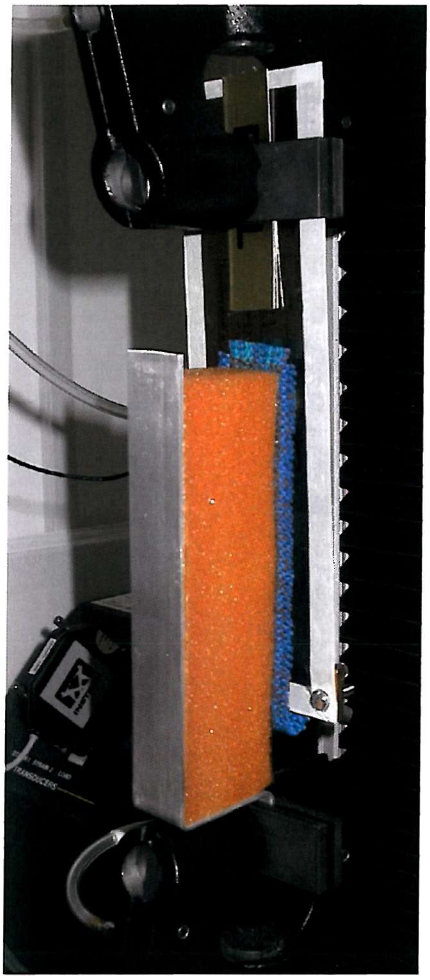
[118] Personal conversation with Peter Fuller, Area Sales Manager, Instron Corporation, 13 January 2006

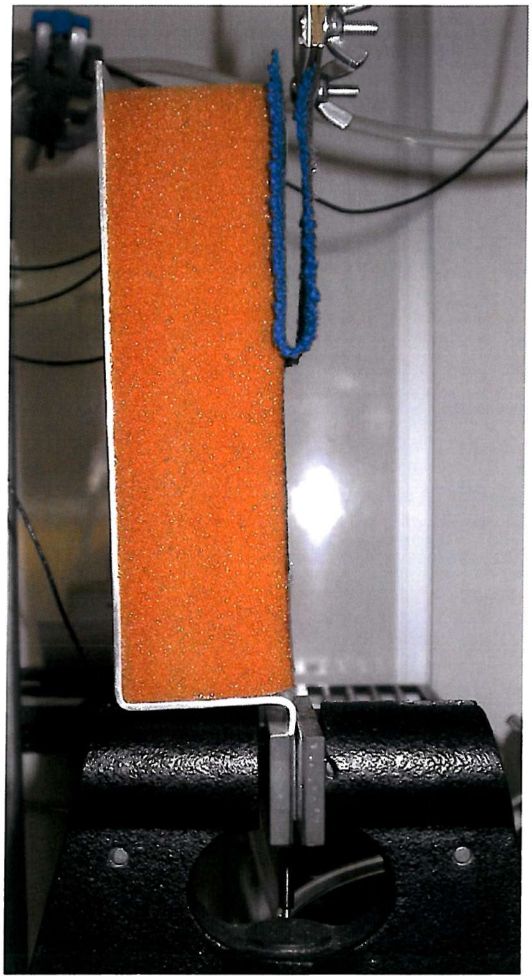
[119] Fabric was prepared in this way for Stage Two as the manual peel process in Stage One had revealed that fabric cut to the exact size of the foam test surface often left whole yarns adhered to the edges of the surface of the foam when peeled away and it was anticipated that this behaviour could affect the mechanical testing results in an erratic way. The fabric preparation technique was observed during a visit with Dr. Irene Karsten, at CCI 10 June 2004.

[120] This process is the end result of a series of test method alterations developed by the author. The alterations are further explained in Section 7.4.1 and were tested with samples of currently commercially produced foam and fabric and a variety of adhesives.

of 180 degrees (Figure 105). A peel rate of 25 mm/min was used and a data point was collected every second and when the load changed by 0.25 Newtons (N) or more.

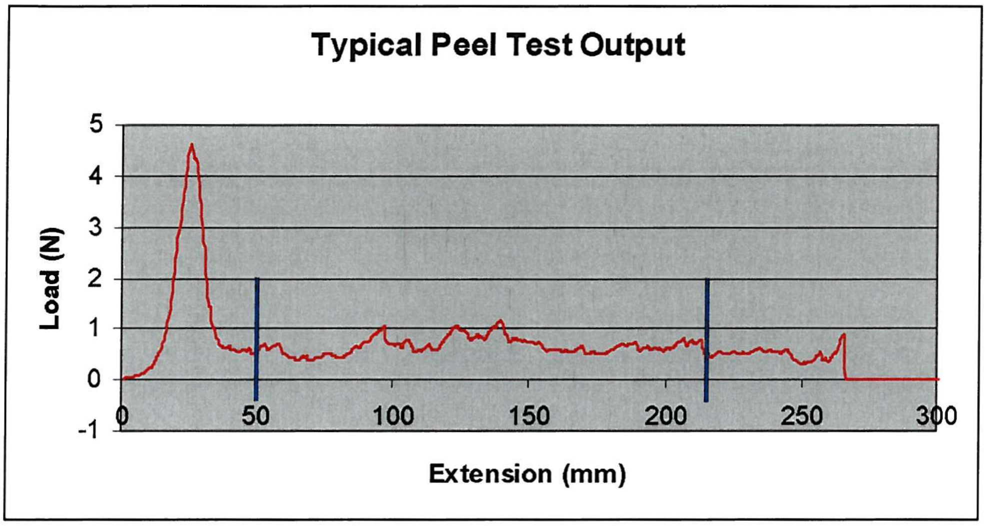


▲ Figure 104: A sample at the start of a peel test with foam secured to an aluminium mount, the mount secured in the lower clamp of the Instron, a metal plate in the upper clamp and the fabric tail gripped in a hinge at the lower end of the plate. (Photo – J. Wickens)



▲ Figure 105: A sample just over half way through a peel. (Photo – J. Wickens)

Data analysis - At the conclusion of each test an average peel strength for each sample was calculated as follows: peel strength (N/mm) = average force (N) / average width of sample (mm). The first and last 50 mm of peel were not included in this calculation. Nor was any data collected after a peel moved away from the foam/adhesive/fabric interface and into the interior of the foam. Additionally, any unusual peaks and troughs in the data which were likely to be the result of external influences were discounted.[121] If the elimination of these data sets did not leave at least 50 mm of good, steady peel then the data was examined to see if less than the first and last 50 mm of peel could be eliminated. If not the entire sample was discounted. Figure 106 shows a graphed data output of one peel test with the data between the blue lines being the data which would be used to calculate average peel strength.



▲ Figure 106: A typical output of data from a peel test. The data between the blue lines would be used to calculate average peel strength.

6.2.2.2 – Creep tests

Sample preparation - Samples were prepared for this test by cutting 75 mm x 75 mm x 40 mm blocks of foam. 85 mm x 85 mm pieces of fabric were also cut and then unravelled along warp and weft to leave a 75 mm x 75 mm woven portion of each sample. Small polyester thread loops were stitched diagonally across the centre two warps and wefts of each piece of fabric. The necessary adhesives were applied to the foam and the fabric was adhered to the adhesive covered surface.

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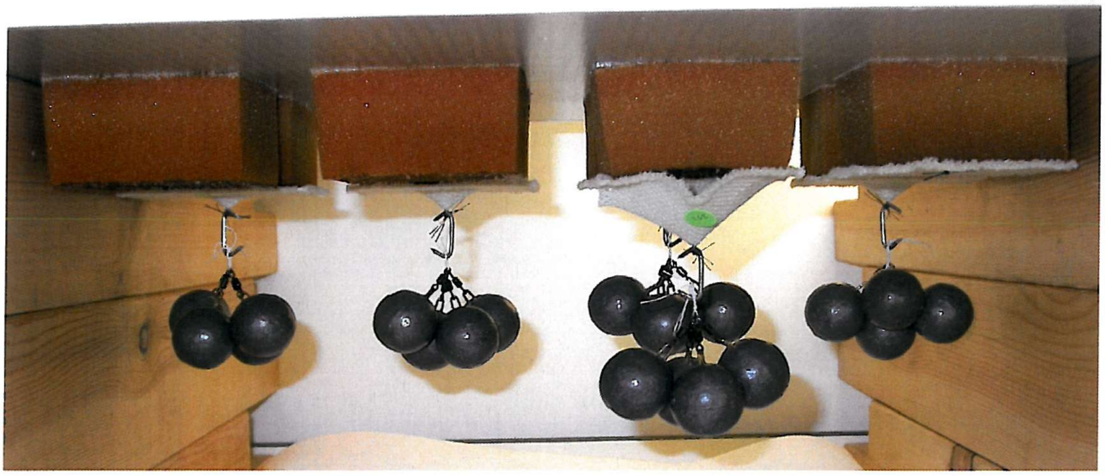
[121] The Instron is located on a work top in the analytical lab at the TCC. If the work top moves while a peel of the strength used in these tests is underway the movement in the work top vibrates the Instron enough to affect the data which is collected. The lab is shared by a large number of staff members and students. Although great care was taken to carry out testing at times when the lab was used by a minimum number of people it was not possible to completely eliminate lab use by others during testing. In turn this meant that occasionally a forceful door or drawer closure caused counter vibration. All such occurrences were noted and data analysis took them into account.

Testing process - One day prior to testing the prepared samples were mounted on a piece of Hexlite® board using Evo-Stik Carpet Adhesive. At the start of the test the board was suspended above a counter top between two wooden supports. A weight of 627 g was then hung on each stitched loop and the sample was observed for 535 min (Figure 107)[122]. If the weight pulled the fabric completely from the foam within the 535 min the time to failure was noted. As the final form of this test did not measure deformation during testing but rather just time to failure it is more accurately referred to as a stress rupture test and it will be referred to as such from here forward (Packham 2005).



▲Figure 107: Several stress rupture tests in progress. (Photo – J. Wickens)

Data analysis – Any sample which exhibited primary failure within the foam was not included in the data analysis. This kept analysis consistent with the peel tests where data collected during a portion of a peel that took place within the foam was discounted. In both cases this was appropriate as the purpose of the tests was to quantify the strength of an adhesive bond not the foam beneath.

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[122] A mass of 627 g and a time limit of 535 min were selected as they set limits for the test which would bring it to conclusion in a day. 627 g was experimentally identified as the amount of weight needed to engineer bond failure so that a bond of apparently useful strength or one that was too weak would fail in a day and a bond which was definitely too strong would not. 535 min (a nine hour work day) was selected as the marker of the end of test in order to make it convenient and simple for a conservator to use (Section 7.4.2).

6.2.3 – Quantifying bond longevity

In order to draw conclusions regarding the relative physical durability of a variety of samples and the long-term serviceability of a material system under certain conditions the practice of accelerated ageing is used (Feller 1994). Typically a set of samples is experimentally evaluated. An 'identical' set is subjected to a set of conditions which speeds up the degradative processes in the samples and then this set is experimentally evaluated in the same way as the first set. The results are then compared. This approach is commonly used to predict the long-term behaviour of artefacts (Stewart et al 1996) and in this case it was employed as the best method for predicting the long-term behaviour of the adhesive bonds carried forward from Stage One to Stage Two.

Accelerated ageing can be carried out in several different ways. Samples can be exposed to high-intensity light. They can be exposed to raised temperatures which might be combined with high humidity levels or cycles of high and low humidity. They can be exposed to acidic conditions (Carr et al 2003; Evenson & Crews 2003; Kaukovalta 2002; Peacock 1983; Rava et al 2004; van Oosten & Aten 1996). All these possibilities were considered with heat ageing in the dark at a controlled humidity level eventually selected as the most appropriate method. By carrying out the work in the dark the degradative reactions not initiated by exposure to ultraviolet radiation or visible light were most likely to be accelerated. As Section 2.4.3 has explained, these were the reactions which were expected to be the primary cause of degradation in the *Globe*. Thus the acceleration of these reactions was most likely to mimic natural processes. The humidity level during the process would be maintained at about 50% RH. This would make it possible to eventually draw conclusions regarding what might happen to the bond if applied to the *Globe* and then displayed in the ideal museum conditions of no ultraviolet radiation exposure, minimal light exposure, 18-22 °C and 45-55% RH. The temperature would be maintained at 80 °C which would make it possible to correlate the results to at least five years of natural ageing and probably more (Section 7.1.2).

Samples were placed inside 13 litre Stewart® boxes (Figures 108 & 109).[123] Each box also contained four beakers of saturated sodium bromide which maintained an

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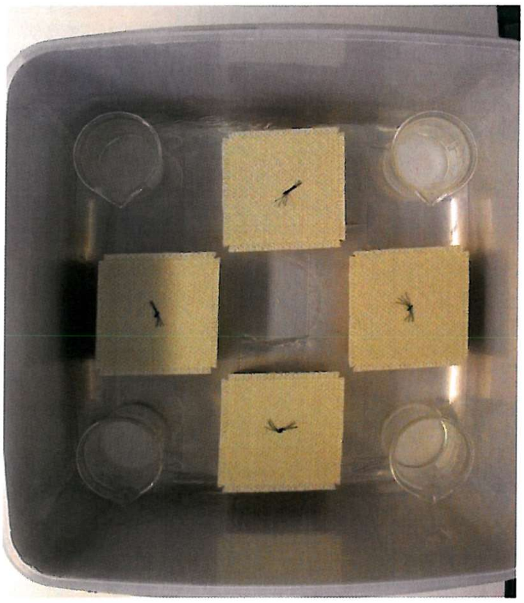
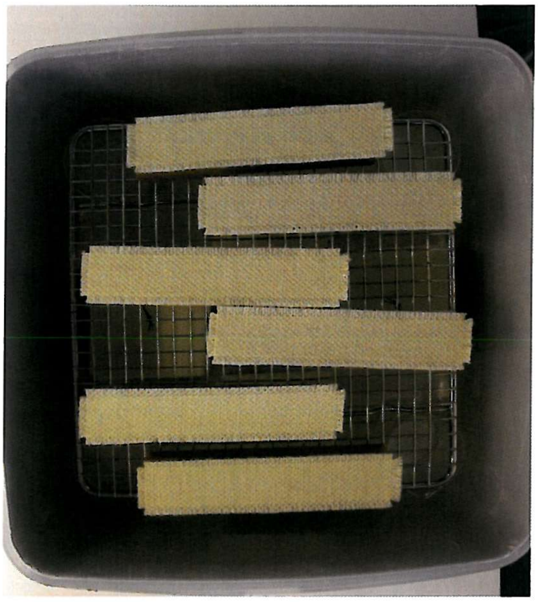
[123] Thickett & Odlyha (in press) reports that these boxes are either polypropylene or polyethylene.

environment of 46.0 +/- 1.5% RH.[124] With lids in place, the boxes were completely sealed with 3M® 425 aluminium tape. This was done to reduce air transfer and was experimentally determined to be necessary to maintain the RH previously described (Thickett & Odlyha - in press).[125] The sealed boxes were then placed in either a Heraeus Instruments Laboratory Air Circulation Oven, model UT 6 P, or a Heraeus Instruments Heating Oven – Air-Circulation Drying Oven, model UT 6060. When the ageing process took more than one week the boxes were opened each week and the beakers of salt solutions which showed reduced levels of liquid were replaced.



▲ Figure 108: Four stress rupture samples and four beakers of saturated sodium bromide on the bottom of a Stewart® box prior to being sealed for accelerated ageing. (Photo – J. Wickens)



▲ Figure 109: Six peel samples in a Stewart® box prior to being sealed for accelerated ageing. They are resting on a metal rack which is supported by the beakers holding the saturated solutions of sodium bromide (Figure 108). (Photo – J. Wickens)

6.2.4 – Recording the location of failure

Following peel and stress rupture tests a visual evaluation, with the naked eye, of each sample would be carried out in order to determine the location of the failure of each bond. Three distinct locations for this failure were identified:

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[124] Labuza (n.d.) states that such a solution will maintain an environment of 51.43 +/- 1.5% RH at 80 °C but pre-tests which monitored the humidity levels in the boxes for 7 days using a Humbug datalogger showed the actual environment was 46.0 +/- 1.5% RH

[125] Personal conversation with Naomi Luxford, conservation science MPhil/PhD student at the University of Southampton, 24 January 2007

- Between the fabric and the adjacent layer of consolidated foam or Beva
- Between the Beva and the consolidated foam
- Within the foam

Additionally, in any one sample failure could take place in any two of the above locations or all three and such multiple locations of failure would be noted.

6.2.5 – Quantifying damage done to fabric and foam

Also, following each peel and stress rupture test the surface of the fabric and foam portions of each sample which had previously been adhered would be examined using a fluorescent illuminated magnifier with 1.75 magnification. Each surface would be assigned a number from 0 to 4 as outlined in Table 24. Any sample receiving a quantifier of 1 or less would be considered appropriate for conservation purposes.

Table 24: The quantifiers used to classify the damage done to fabric and foam during peel and stress rupture tests.

Evaluated Surface	Quantifier	Notes for Quantification
Foam	0	No visible damage
	1	Scattering of individual fibres on the foam surface
	2	Light covering of fibres over most of the foam surface
	3	Heavy covering of fibres over most of the foam surface
	4	Rip or tear in the fabric
Fabric	0	No visible damage
	1	Scattering of pencil tip size or less pieces of foam/adhesive with perhaps a few larger bits at the edges of the fabric surface
	2	Less than 25% of the fabric surface covered with foam/adhesive and the pieces are no larger than 2 mm^2
	3	More than 25% of the fabric surface covered with foam/adhesive and/or the pieces are larger than 2 mm^2 and less than 5 mm^2
	4	Failure within the foam at any point in an area 5 mm^2 or larger

6.2.6 – Summary

Peel tests and stress rupture tests were thus defined to quantify bond strength. Heat ageing was selected as the most appropriate technique for considering bond longevity.

Guidelines were in place to characterise and quantify surface distortion before bonding and damage to fabric and foam after strength testing. The data collected by these methods would be used to evaluate the continued viability of each bond carried forward into Stage Two. The results of this defined testing, as carried out in two rounds, and the implications of those results are discussed in the following sections.

6.3 – Two rounds of testing

The first round of testing would set out to determine if after further analysis one or more of the four identified adhesive/concentration/reactivation combinations still appeared to be a viable conservation solution for the *Globe*. The second would further analyze the most promising solution with the ultimate goal of determining whether it could be strongly recommended for use in the conservation of the chair.

The experimental protocols would be the same as those used in Stage One, with the following exceptions. The number of replicates used in each sample set would be increased from the three used in the last round of Stage One to six for each peel test and four for each stress rupture test. The size of the foam blocks for these samples as well as the specific way in which the fabric would be prepared was adjusted to meet the requirements of the peel and stress rupture tests as previously laid out (Section 6.2). Due to the size of the samples as compared to the size of the hand lining iron heat reactivation would have to be carried out by reactivating one half of each sample at a time. In so doing, when the second half of the sample was reactivated the heat lining iron would overlap the first reactivation area by 1 cm in order to compensate for the fact that the iron is slightly cooler at the edges.[126] Heat reactivation would also be carried out using a support for the iron as Stage One: Round Two had revealed that the weight of the iron and the size of the sample made it difficult to hold the iron in place during a 90 or 180 second reactivation without compressing the foam or causing movement of the fabric. The size and shape of the peel and stress rupture samples for Round Two was expected to make this problem worse. A support would make it possible to keep the iron stationary and assist in applying steady, even heat to the samples.

6.3.1 – Round one - the process

12 peel samples and eight stress rupture samples were prepared for each of the four identified adhesive/concentration/reactivation combinations. In order to work within the limits set by necessary preparation time, space in the ageing ovens and equipment available for testing, samples were prepared in two sets. The Lascaux only and the

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[126] This method was developed and used with good results by conservators working on a large project for a private client at the Textile Conservation Centre, University of Southampton in 2003/4.

Lascaux and Beva samples were prepared and analyzed together. Two weeks later the Impranil and Beva samples and the Plextol and Beva samples were prepared and analyzed. For each sample set, liquid adhesives were applied in one morning and left to cure either until apparent dryness (a few hours) or for 24 hours, as identified in Stage One. Once the ideal curing time was reached fabric was adhered to the samples again using the reactivation parameters identified in Stage One. Five days after the liquid adhesives were first applied six peel and four stress rupture samples from each adhesive/concentration/reactivation combination were sealed in a Stewart® box[127] as described in Section 6.2.3. The boxes were then placed in the described air circulation ovens for one week of accelerated ageing. On the same day the other six peel and four stress rupture samples were subjected to the bond durability tests as described above. [128] When the aged samples were removed from the ageing ovens and boxes they were left for 24 hours at ambient conditions and then subjected to the same bond durability tests.

6.3.2 – Round one - the results

Overall, the testing revealed the following results. Impranil caused the greatest amount of surface area shrinkage, Lascaux the least with Plextol in between. The peel tests and stress rupture tests showed that before ageing the bonds ranked from weakest to strongest as follows: Lascaux only < Impranil and Beva < Lascaux and Beva < Plextol and Beva. After ageing the bond strength changed but the order of the bonds from weakest to strongest did not. Overall damage done to foam and fabric was acceptable for all Lascaux only bonds. It was unacceptable for all Lascaux and Beva bonds and Plextol and Beva bonds. In three of the four bond durability tests it was acceptable for the Impranil and Beva bonds with the damage to foam during stress rupture tests before ageing being the exception. The location of failure of the bond was acceptable for all Lascaux only bonds. It was acceptable for 18 of the 20 Impranil and Beva bonds. It was unacceptable for 18 of the 20 Lascaux and Beva bonds and all of the Plextol and Beva bonds. Each of these conclusions in presented in further detail in the following sections.

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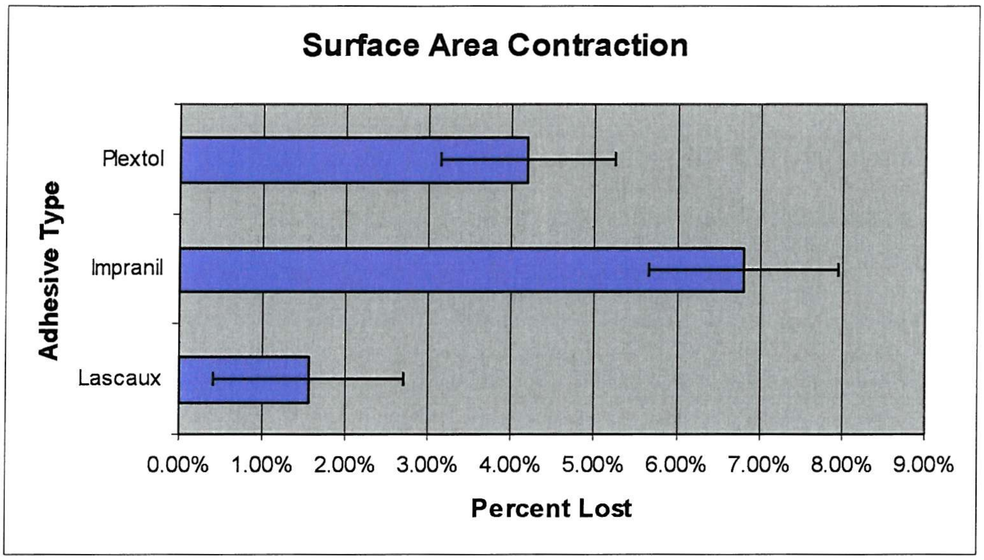
[127] A separate box was used for each adhesive/concentration/reactivation combination.

[128] To be most consistent with the work carried out in Round One peel and stress rupture tests on unaged samples would have been carried out 24 hours after reactivation had taken place. However, the timeline for overall work and periods of immovable closure of the TCC made this impossible. As a slight variation in time between reactivation and bond strength testing was not expected to be significant with respect to bond results the variation was determined to be acceptable.

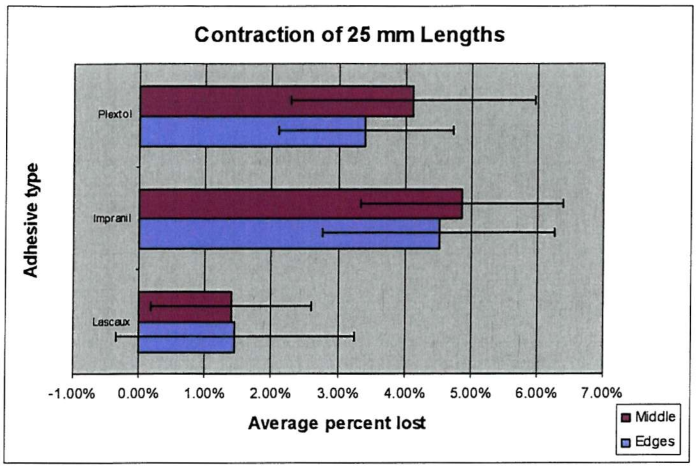
6.3.2.1 – Dimensional changes

Using the recorded measurements previously described an average length and width of each sample before liquid adhesive application and after optimum curing was calculated. From these figures a percentage of surface area lost due to contraction of the foam during the drying/curing process was determined. Figure 110 shows that when the values for surface area contraction are averaged across all peel and stress rupture samples within a particular adhesive type Impranil caused the most shrinkage, Lascaux the least with Plextol in between.

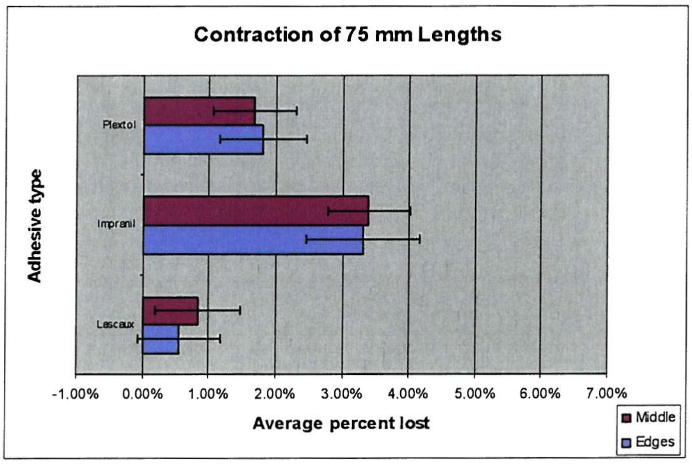


▲ Figure 110: The percentage of surface area lost to contraction as liquid adhesives dried/cured. The Plextol and Impranil values represent an average of 12 peel samples and 8 stress rupture samples. The Lascaux value represents and average of 24 peel samples and 16 stress rupture samples.

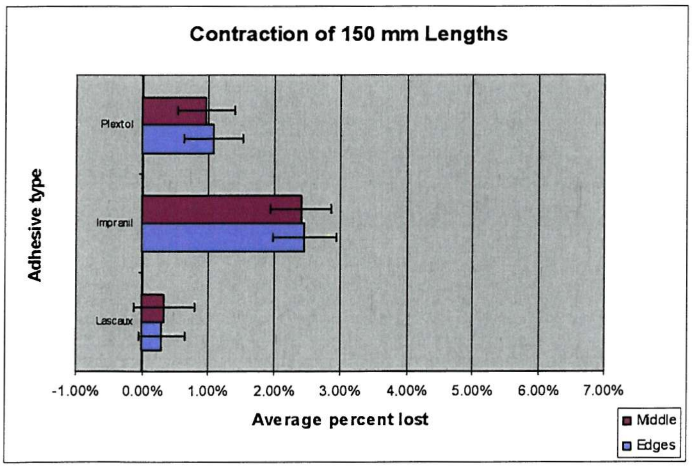
When considered further it was found that the shrinkage was most predominant in the shorter lengths of the samples as Figures 111 - 113 illustrate. Each figure charts, by adhesive type, the average percentage reduction for measurements recorded at the edge of each sample and the middle of each sample. When adhesive types are examined across charts it is always the case that the greatest percentage is lost with the shortest dimensions (25 mm lengths of the rectangular peel samples), the smallest percentage is lost with the longest dimensions (150 mm lengths of the rectangular peel samples) and the middle dimension (75 mm lengths of the square stress rupture samples) loses a percentage that falls between the two extremes. However, when experimental error is considered this trend is not so clear. This is partially due to the fact that in a few cases measurements showed that samples actually expanded rather than contracted during the drying/curing process. This negative percentage reduction makes the standard deviation in each average quite large.



▲ **Figure 111: The average percentage reduction of the 25 mm lengths of the peel samples resulting from contraction during the drying/curing of liquid adhesives.**

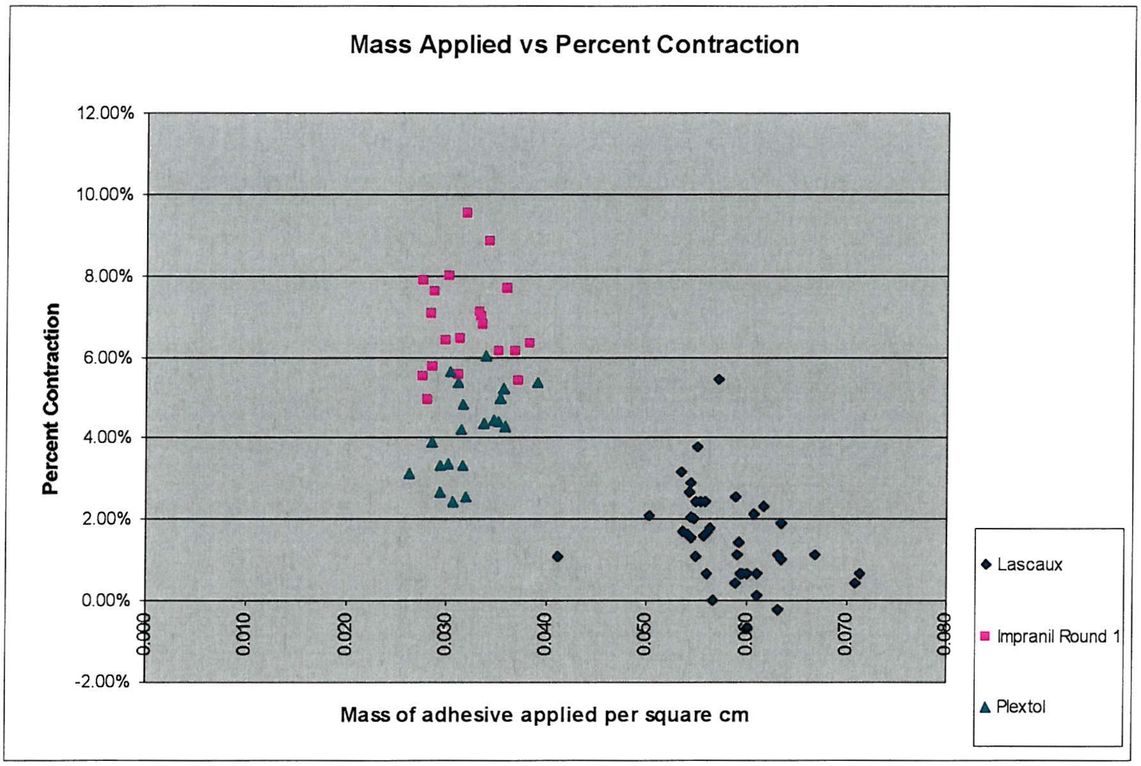


▲ **Figure 112: The average percentage reduction of the 75 mm lengths of the stress rupture samples resulting from contraction during the drying/curing of liquid adhesives.**



▲ **Figure 113: The average percentage reduction of the 150 mm lengths of the peel samples resulting from contraction during the drying/curing of liquid adhesives.**

The previous charts also provide a comparison of the shrinkage in the internal dimensions as opposed to that which occurred at the edges of each sample. This comparison shows there is no significant difference between the two. Additionally whether or not the mass of adhesive applied per square centimetre affected the percentage of surface area lost during the drying/curing process was investigated. While there was no evidence that clearly suggested that a greater applied mass caused more or less shrinkage what was found was that the mass of adhesive applied and the shrinkage caused by that mass were relatively consistent within adhesive type. This can be seen in the clustering of data points in Figure 114 which charts mass of adhesive applied per square centimetre versus percent of original surface area lost.

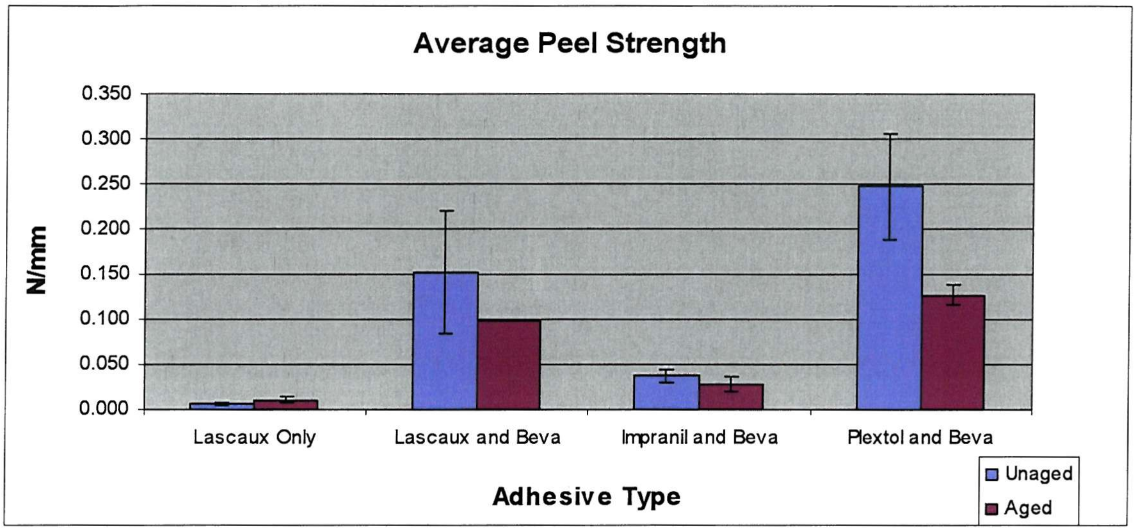


▲ **Figure 114: For each sample, a plot of the average mass of liquid adhesive applied per square centimetre versus the percent of surface area contraction resulting from the adhesive drying/curing process for each sample.**

Thus the drying/curing process of the liquid adhesives did distort the surface of the foam to which the adhesive had been applied. The amount of distortion was generally consistent within adhesive type and can be correlated with the consistency of the mass of adhesive applied. As the length of each sample increases the impact of the distortion is reduced.

6.3.2.2 - Peel strength

As outlined above, the average peel strength, in N/mm, was calculated for each sample (Section 6.2.2.1). Using these figures an average peel strength for each sample set before and after ageing could be determined. Figure 115 charts these averages. The bars represent the average of six samples with three exceptions. There were only four viable peels in the Lascaux and Beva samples before ageing and two after ageing and only five viable peels in the Plextol and Beva samples after ageing.



▲ **Figure 115: The average peel strength for each sample set before and after ageing. Standard deviation was calculated and is represented by error bars for all but the Lascaux and Beva samples after ageing as the figure is only represented by two viable peels (0.0960 & 0.0998 N/mm).**

This figure clearly shows that the Plextol and Beva bonds are the strongest, followed by the Lascaux and Beva bonds, followed by the Impranil and Beva bonds with the Lascaux only bonds being the weakest. This strength order remains consistent both before and after ageing. Although when experimental error is taken into account the Plextol and Beva and Lascaux and Beva bonds may be quite similar in strength.

Figure 115 also shows that two of the four bonds clearly lose strength in the ageing process. The Impranil and Beva bonds are very similar in strength before and after ageing. The apparent slight increase in strength shown by the Lascaux only bonds does not appear to be significant when considered in relation to experimental error. However, if significant it can probably be explained by one of two factors. It may be the result of the reactivation of some of the naturally aged polychloroprene based adhesive during extended exposure to raised temperatures which then added to the strength of the bond in the samples. It might also be the result of some cross-linking in the adhesive during the ageing process.[129]

Finally, Figure 115 shows that while the manual peel tests of Stage One: Round Two evaluated the four bonds represented by the blue bars as being very similar in strength, when measured quantitatively there are clear differences. These are relatively small (<0.25 N/mm[130]) but nonetheless significant as the further data presented in the following pages will demonstrate.

6.3.2.3 - Stress Rupture

The samples for the stress rupture tests were considered viable for use in analysis if they failed within one work day (535 min) and the primary location of the failure was not in the foam (Section 6.2.2.2). Complete failure was defined by the moment the attached weight had pulled the bonded fabric completely from the foam. Table 25 summarizes the viability of samples by adhesive type before and after ageing with the maximum number of samples in each category being four.

Table 25: The viability of unaged and aged stress rupture samples in Round One.

Adhesive Type	**Unaged or aged**	**Number of viable samples**	**Number of samples failing in a day but primarily within the foam**	**Number of samples not failing within a day**
Lascaux only	Unaged	4	-	-
	Aged	4	-	-
Lascaux and Beva	Unaged	-	-	4
	Aged	-	1	3
Impranil and Beva	Unaged	2	2	-
	Aged	3	1	-
Plextol and Beva	Unaged	-	2	2
	Aged	-	2	2

The average time to failure of the viable samples is summarized in Table 26. This data is consistent with the peel results. The Lascaux only bonds are weaker than the Impranil

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[129] A suggestion made by Dr. Paul Garside, Postdoctoral Research Fellow, TCC, University of Southampton

[130] One Newton equals approximately 100 g.

and Beva bonds. The Lascaux only bonds gained a very slight amount of strength in the ageing process and the Impranil and Beva bonds lost strength. The fact that the bonds of the other two adhesives did not fail within 535 min is also consistent with the peel strength results. These other two adhesives produced the stronger bonds in the peel tests and their lack of complete failure in 535 min shows that in stress rupture tests the bonds are stronger as well.

Table 26: The average time to failure for all viable stress rupture samples in Round One.

Adhesive Type	Unaged or aged	Average time to failure in min:s (range)
Lascaux only	Unaged	0:00 (0:00 – 0:00)
	Aged	0:02 (0:00 – 0:08)
Impranil and Beva	Unaged	153:22 (122:23 – 184:22)
	Aged	12:13 (4:52 – 19:34)

6.3.2.4 - Location of failure

It has been explained that the ideal place for the newly established bond to fail is between the Beva and the consolidated foam surface for three of the adhesive/concentration/reactivation combinations being tested. This location of failure would protect fabric and foam during the failure process and allow for a controlled removal of the Beva from the fabric surface (Section 5.3.2.5). As no Beva was required for the Lascaux only bonds, in order for these bonds to be considered appropriate adhesive or cohesive failure needed to take place between the fabric and consolidated foam surface doing no more than what had been identified as acceptable damage.

The left hand column of Table 27 lists the seven single or combined possible locations of failure for the adhesive bonds. The remaining columns list, by adhesive type, the number of bonds failing in each location with a total number of bonds for each adhesive type being 10 unaged and 10 aged. The cells shaded in red highlight the bonds which failed in the ideal location, as described above. Of particular note is the fact that all 20 of the Lascaux only bonds failed as desired. Additionally, eight of the 10 Impranil and Beva samples evaluated before ageing failed exactly as it was hoped the bond could be engineered. After ageing, it was discovered that in these samples the Beva fractured into tiny pieces leaving approximately 50% of the film on the fabric and 50% of the film on the consolidated foam surface. This type of failure slightly increased the damage done to the fabric in the process but not above acceptable levels and left an adhesive residue that appeared might be more easily removed than that left in the pre-aging tests. Therefore, this failure was subsequently identified as acceptable bringing the acceptable failure in the Impranil and Beva bonds to 18 of the 20 samples. The location of failure was unacceptable in all 20 of the Plextol and Beva bonds and in 18 of the 20 Lascaux and Beva bonds.

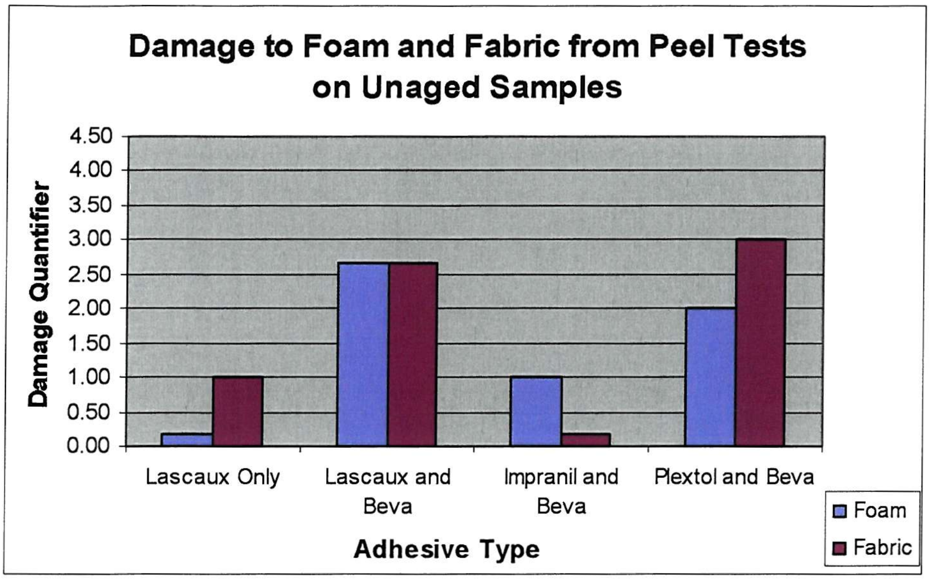
Table 27: The location of bond failure for all unaged and aged samples subjected to peel or stress rupture tests in Round One. The samples which failed in locations which were identified as ideal are highlighted in red and purple.

Possible Locations for Bond Failure During Bond Durability Testing	**Lascaux only**		**Lascaux and Beva**		**Impranil and Beva**		**Plextol and Beva**	
	Unaged	**Aged**	**Unaged**	**Aged**	**Unaged**	**Aged**	**Unaged**	**Aged**
Between the fabric and the adjacent layer of consolidated foam or Beva	10	10	2	3			3	1
Between the Beva and the consolidated foam			2		8			
Within the foam			1	1	1		3	3
Between the fabric and the Beva, and between the Beva and the consolidated foam						10		
Between the fabric and adjacent layer of consolidated foam or Beva, and within the foam			4	6			3	6
Between the fabric and the Beva, between the Beva and the consolidated foam, and within foam								
Between the Beva and the consolidated foam, and within foam			1		1		1	

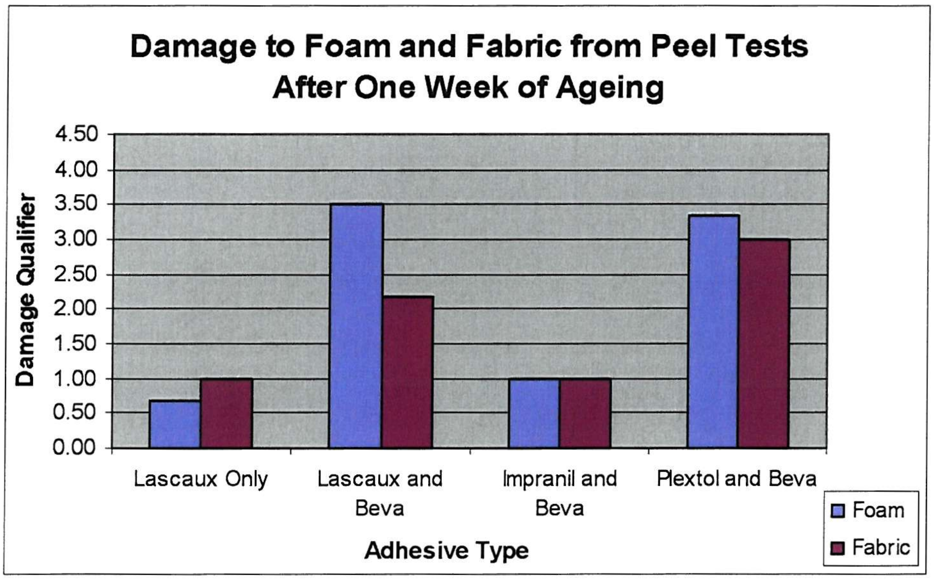
6.3.2.5 – Damage to fabric and foam

During the stress rupture tests it was observed that the behaviour of the test changed significantly as failure reached the outer edges of the sample. Initially the force applied in the form of a static weight pulled on the sample with even distribution causing slow, steady bond failure. Once the weight was supported by an adhesive bond remaining at only some of the edges or corners the bond failure often became quick and dramatic. A corner of the fabric would be pulled away from the sample. As it dropped the weight would swing causing enough force to pull another corner away with more force inducing failure in the foam that might not have taken place if the weight had not swung following the release of the first corner. In order to eliminate results which were clearly affected by these irregular forces the damage to stress rupture samples was only evaluated across a circle 55 mm in diameter placed at the centre of the foam and fabric. The entire surface of each peel sample was evaluated. The evaluation of both types of samples used the scale described in Section 6.2.5.

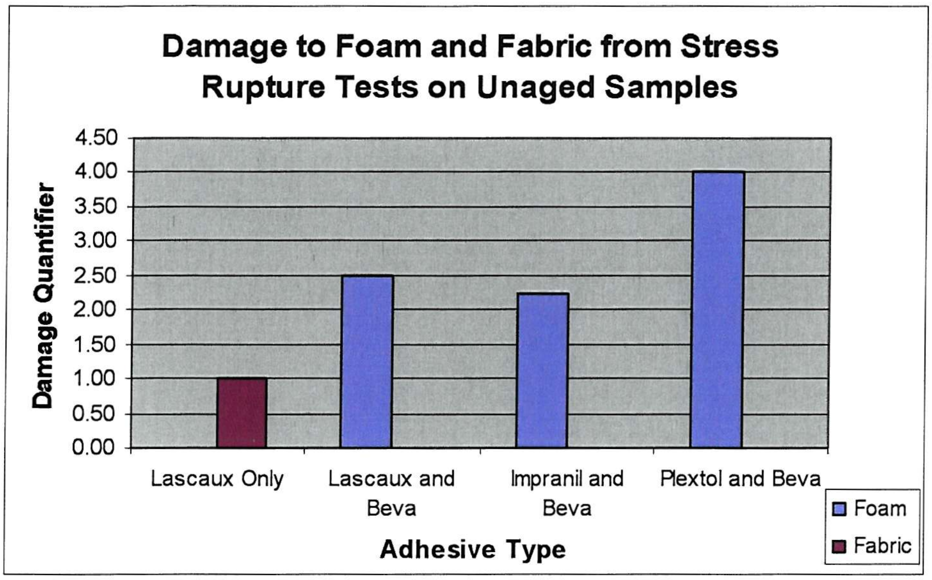
Figures 116 - 119 present the results of these evaluations before and after ageing with peel tests and stress rupture tests charted separately. Each bar on each chart represents the average quantifier for six peel samples or four stress rupture samples. In all but one case the damage done to samples after ageing was either the same or more. The one exception was that the average damage to the fabric done by peel test in the Lascaux and Beva samples dropped by almost one after ageing. When damage to foam and fabric are considered in combination the Lascaux and Beva bonds and the Plextol and Beva bonds did too much damage to be appropriate for conservation purposes as in all cases the quantification for one or both materials was above one. The Lascaux only samples were quantified below one in all cases making them appropriate bonds with respect to damage done. The Impranil and Beva bonds were quantified as appropriate for conservation in three of the four tests. In the stress rupture tests before ageing the fabric was not damaged but the foam damage was quantified at 2.25. This was due to the fact that two of the four samples suffered failure in the foam which was quantified as four.



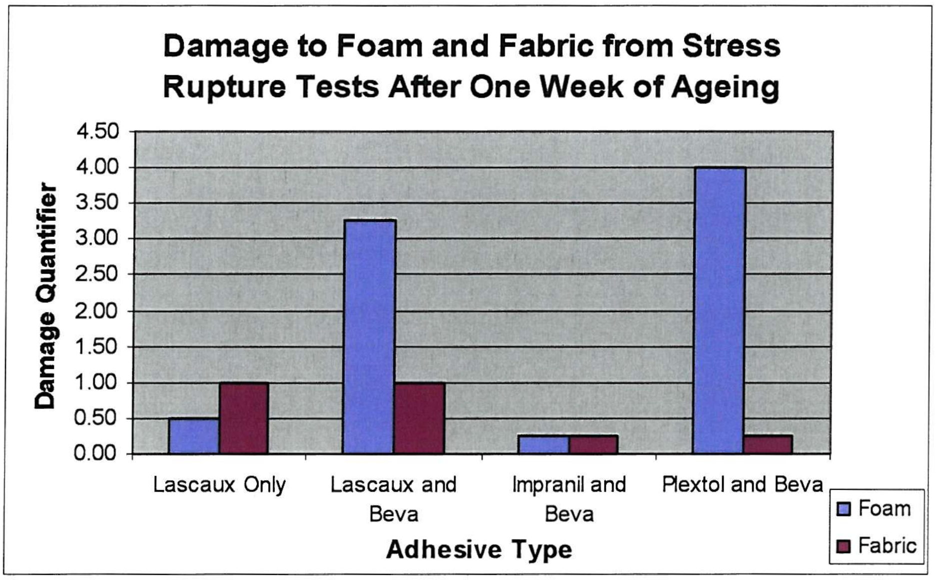
▲ **Figure 116: The quantified damage done to fabric and foam during peel tests on unaged samples in Round One.**



▲ **Figure 117: The quantified damage done to fabric and foam during peel tests on aged samples in Round One.**



▲ Figure 118: The quantified damage done to fabric and foam during stress rupture tests on unaged samples in Round One. The data which appears to be missing from each adhesive type reflects foam or fabric damage which was quantified at 0.00.



▲ Figure 119: The quantified damage done to fabric and foam during stress rupture tests on aged samples in Round One.

6.3.3 – Round one - the implications

The above data was then used to consider the viability of each bond. Was it too strong or too weak before and/or after a period of accelerated ageing? Too strong being that the bond induced damage in the foam or fabric when it was pulled apart rather than failing within the adhesive or at the adhesive/adherend interface. Too weak being that it was clear the bond could not support fabric in the context of the *Globe*. Did the cured adhesive distort the surface of the foam in a way that was not imagined to be able to be accommodated in the context of the *Globe*?

The Lascaux only bonds were identified as definitely too weak both before and after ageing. This was based on the fact that in pre-tests four stress rupture samples with Lascaux only bonds developed areas of failure when they were suspended for 24 hours with no weight added to the samples. When weight was hung on these samples they failed instantly in all four cases. Peel samples prepared at the same time and with the same materials as these stress rupture samples had the average bond strength of 0.014 N/mm. The peel samples evaluations just described for Stage Two: Round One showed an average strength of 0.006 N/mm before ageing and 0.011 N/mm after ageing. Thus the peel samples evaluated in Round One were even weaker than those evaluated in the pre-test. The extreme weakness of these bonds was corroborated by observation of the peeling behaviour. As the Instron pulled up on the fabric to peel it from the foam the fabric separated from the foam before enough force was applied to the sample to bring the peel angle to 180 degrees. Although this bond caused just about no damage to fabric or foam when it was pulled apart, a positive quality in conservation terms, it was clearly not strong enough to support the fabric in the *Globe*. Experiments with this bond had begun in initial testing by mixing the Lascaux at 15% w/v. In the experiments just described it was prepared at 75% w/v. A variety of reactivation temperatures and times had been tried. If the bond was going to be strengthened to an appropriate level experimentation would have to begin again. It was therefore eliminated from further consideration in this project.

The Plextol and Beva and Lascaux and Beva bonds on the other hand were identified as definitely too strong. The Plextol and Beva bonds had caused failure within the foam in 16 of the 20 samples and unacceptable levels of damage to the fabric in the other four. The Lascaux and Beva had caused failure within the foam in 13 of the 20 and unacceptable levels of damage to the fabric in five of the other seven. These levels of damage identified all the bonds as inappropriate for conservation purposes.

With respect to peel strength the strongest Lascaux only bond was calculated at 0.014 N/mm. The weakest Plextol and Beva or Lascaux and Beva bond was calculated at

0.071 N/mm. Thus, if it existed, a bond that was strong enough to support the fabric in the *Globe* but at the same time do only acceptable damage to the foam and/or fabric if the bond failed presumably must fall within the range these two figures established. In all cases before and after ageing the Impranil and Beva bonds did with the average bond strength before ageing being 0.032 N/mm and the average bond after ageing being 0.028 N/mm. Thus, based on peel strength the Impranil and Beva bonds were likely to be a good conservation option.

With respect to strength as it relates to location of bond failure and damage done to fabric and/or foam in the process, all 12 Impranil and Beva peel samples and six of the eight stress rupture samples were of an appropriate strength. They had failed in the ideal location causing no damage or minimal damage quantified at a level that had been defined as acceptable. In two stress rupture samples failure had unacceptably taken place largely or completely within the foam. However, since the load applied in the stress rupture tests was more than 170 times greater than the mass of fabric a 75 mm x 75 mm portion of foam in the *Globe* needs to support this anomaly was not seen to be a particular cause for concern. As has been pointed out by Packham (2005:496-499) in extreme situations bonds do not always fail in the weakest place. He uses perforated paper which does not tear at the perforation as an example. In all likelihood the damage seen in the stress rupture tests is evidence of a similar type of behaviour.

So, based on bond strength, the Lascaux only samples were definitely eliminated. The Plextol and Beva and Lascaux and Beva solutions could only reasonably be taken forward if a way to weaken the bonds could be identified which resulted in bonds which caused significantly less damage to fabric and foam during rupture. The Impranil and Beva bonds however showed clear signs of still being appropriate with respect to bond strength and quality suggesting the combination should be taken forward to Round Two.

However, Impranil had caused the greatest amount of shrinkage in the surface of the foam during the drying/curing process. If the shrinkage was so significant the changes to the foam could not be defined as acceptable and accommodated in the conservation process of the *Globe* an Impranil and Beva bond would not be an appropriate solution in this case. Impranil had caused an average surface area contraction of 6.81% over all samples with a maximum contraction of 9.51% in one peel test sample. However, this contraction was observed in small foam blocks with a surface area less than 1% of the surface area of an actual shell upholstery pad in the *Globe*. Section 6.3.2.1 has presented results which suggest that as surface dimensions of the foam increase the percentage contraction of the surface due to drying/curing of liquid adhesives decreases. This in turn suggests that dimensional changes, due to the drying/curing of Impranil, in a foam pad the size of that in the *Globe* would be likely to be of an insignificant amount. If the Impranil and Beva combination was ever selected for application to the *Globe* this supposition would need to be further tested prior to conserving the chair. However, on the strength of the previous supposition it was reasonable to eliminate surface contraction as a strong concern in the decision making process and carry the Impranil and Beva combination forward for one final round of testing.[131]

6.3.4 – Round two - the process

For Round Two, 30 peel samples and 12 stress rupture samples were prepared using the exact procedure used in Round One with the exception of the fact that the naturally aged fabric described in Section 4.1.2 replaced the surrogate fabric which had been used in all testing to date. This introduced for the first time a degraded polychloroprene based adhesive residue on the test fabric as well as the foam. It also meant that a fabric of an identical rather than similar weight and weave structure to that on the *Globe* was being used. The inclusion of this degraded adhesive coated fabric for a final round of testing would make the results of such work even more directly applicable to the *Globe* than the results produced to date.

As in Round One the samples were prepared on one day. Eight days[132] after this preparation six peel and four stress rupture samples were subjected to the bond durability tests used in Round One. The remaining samples were placed in the ageing ovens as previously described. This time however samples would be subjected to ageing

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[131] This decision was strengthened by an opinion expressed by Kathryn Gill and Dr. Paul Wyeth during a personal conversation with the author on 29 March 2007. The opinion was that the results of further testing of the Impranil and Beva adhesive/concentration/reactivation combination would be useful for those considering the conservation of other foam upholstered chairs even if it eventually proved to be inappropriate for the *Globe*.

[132] A time period of five days was used in Round One. However, as the time between reactivation and testing had to vary between Stage One: Round Two and Stage Two: Round One due to the timeline for overall work and periods of immovable closure at the TCC the same was true for Stage Two: Round One and Round Two. As with the previous explanation, Section 6.3.1, Footnote 128, the variation was acceptable as the time delay was not expected to be significant with respect to bond results.

conditions for up to four weeks rather than just one which would allow results to be correlated to five years or more of natural ageing (Section 6.2.3). Six peel samples would be removed from the ageing ovens at time points of 24 hours, 1 week, 2 weeks and 4 weeks. Four stress rupture samples would be removed at 24 hours and 4 weeks.[133] As with Round One, after removal from the ageing ovens and boxes samples were left for 24 hours at ambient conditions in the lab before being subjected to peel and stress rupture tests. By removing and analyzing samples at intermediate time periods as well as the end of the ageing process it would be possible to carry out a more detailed assessment of ageing behaviour rather than only an assessment of a final state.

6.3.5 – Round two - the results

A slight increase in the surface area shrinkage brought on by the drying/curing of the liquid Impranil was observed as compared to that recorded in Round One. It appears this increase can be correlated to a parallel increase in the mass of applied adhesive. With the exception of those recorded after 24 hours of ageing, the peel strength of all bonds tested remained within the range established in Round One as still possibly viable for the conservation of the *Globe*. Those recorded after 24 hours of ageing were just slightly outside the high end of this range. The stress rupture tests again confirmed the general results of the peel tests with respect to bond strength. As to location and level of damage, 39 of the 42 samples failed in the ideal location causing only acceptable levels of damage to fabric and foam. Again, the three which failed in undesirable locations were all stress rupture samples and in each case the failure caused unacceptable levels of damage to the foam. The following sections provide more detail as to how these conclusions were reached.

6.3.5.1 – Dimensional changes

In this round, the amount of shrinkage in the surface area of the foam to which the liquid Impranil was applied increased by an overall average of 2% from the values calculated in Round One. These values are presented in Table 28 with the figures from

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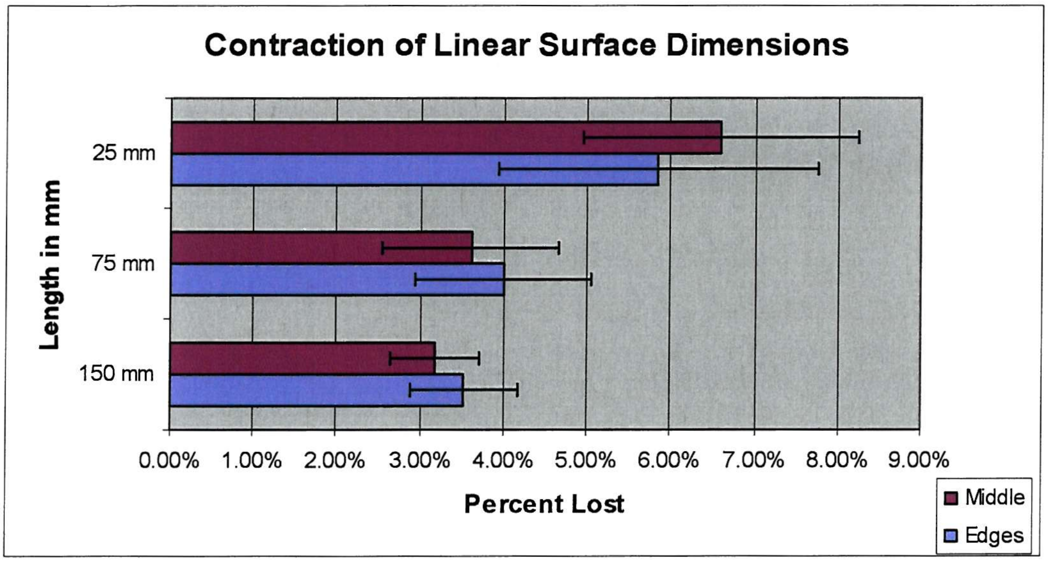
[133] Beakers of saturated salts were replaced each time a box was opened to remove samples and the boxes were opened at three weeks of ageing for the specific purpose of renewing the salt solutions as pre-tests had only determined that the solutions maintained the required humidity levels for a period of one week.

Round One representing 12 peel and eight stress rupture samples and the figures from Round Two representing 30 peel and 12 stress rupture samples. The average linear dimensional changes represented in these overall averages of surface area lost are shown in Figure 120.

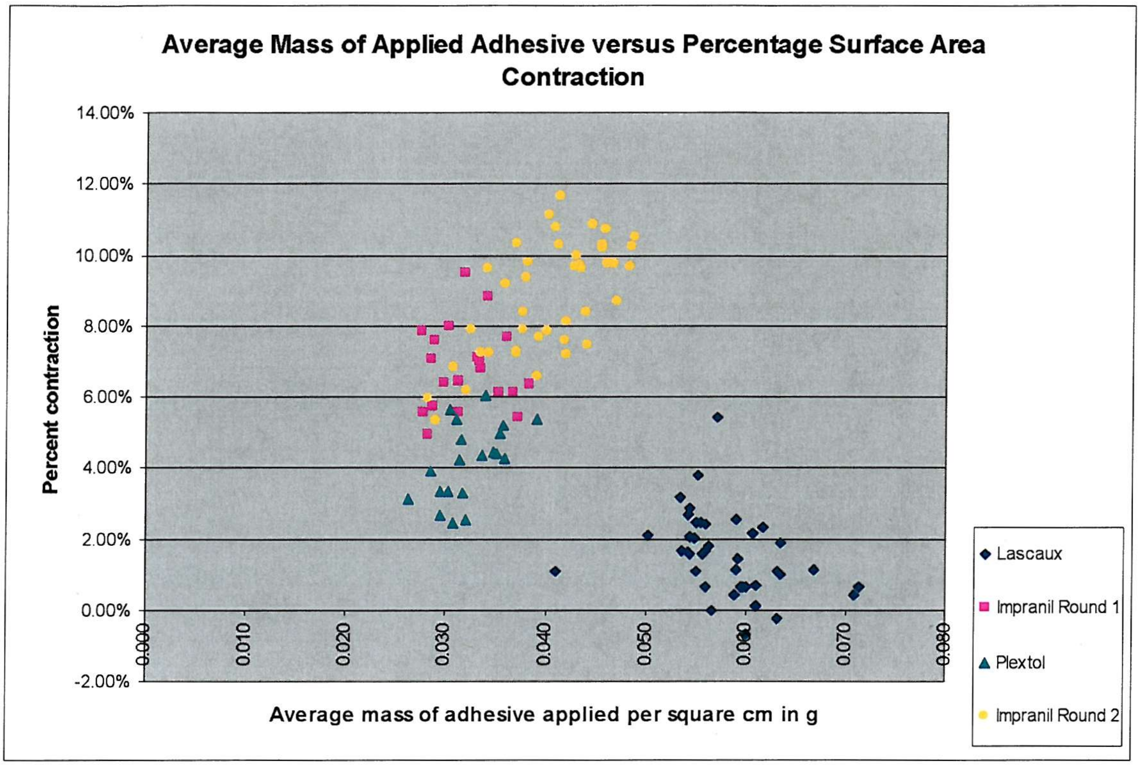
Table 28: The percentage of surface contraction caused by drying/curing Impranil. Figures are presented for total peel samples and stress rupture samples for Round One and Round Two.

	Average of peel samples	Average of stress rupture samples
Round One	7.0%	6.6%
Round Two	9.3%	7.6%
Percent Change	+2.3%	+1.0%



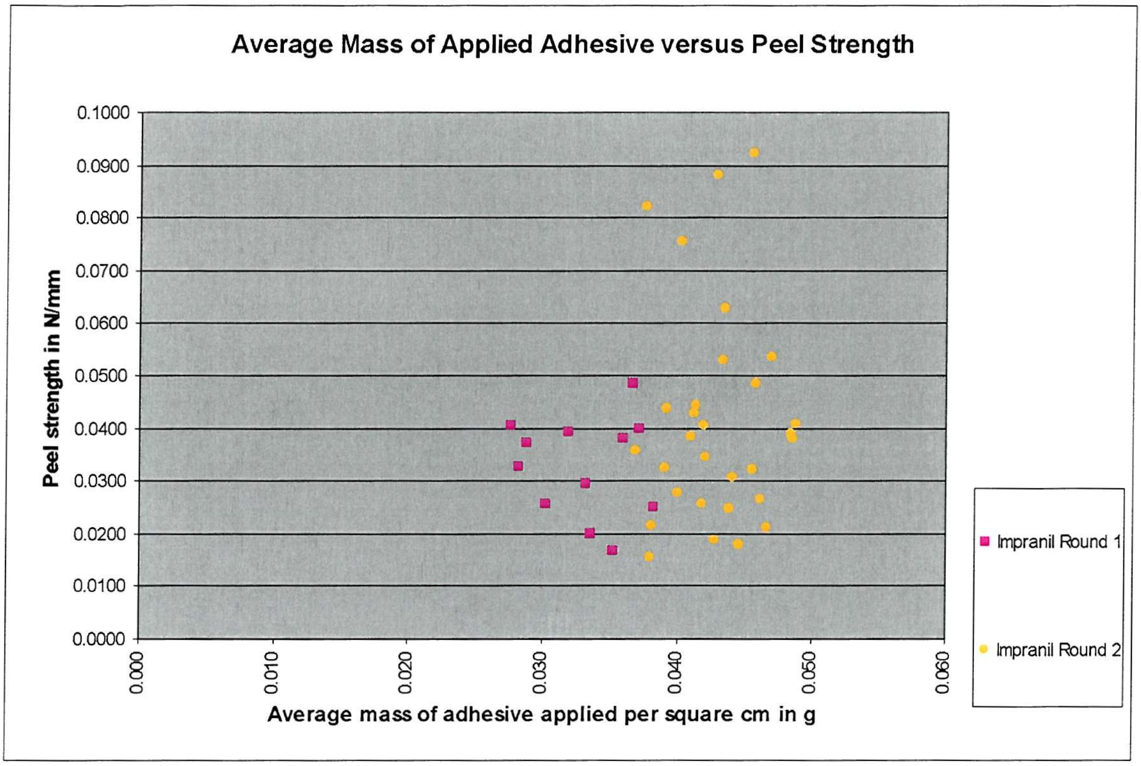
▲ Figure 120: The average percentage lost in linear dimensions due to surface contraction during the drying/curing of Impranil in Round Two. The 75 mm values represent 12 stress rupture samples. The 150 mm and 25 mm values represent 30 peel samples.

Figure 121 shows the mass of adhesive applied per square centimetre versus the percentage of surface area contraction. The data points for the samples prepared in Round Two have been overlaid in yellow onto those previously plotted in Round One. With the addition of these points a trend is now apparent for Impranil. The percentage of surface area contraction increases with an increase in the amount of adhesive applied. As the figure also shows that generally the amount of adhesive applied to each sample was greater in Round Two than in Round One it provides an explanation for why the overall average for surface area contraction increased (Table 28, Page 214) from Round One to Round Two.



▲ Figure 121: The average mass of applied adhesive for each sample from Round One and Round Two plotted against the percentage of surface area lost to contraction. The data points for the samples prepared in Round Two have been overlaid on Figure 114, Page 202 from Round One.

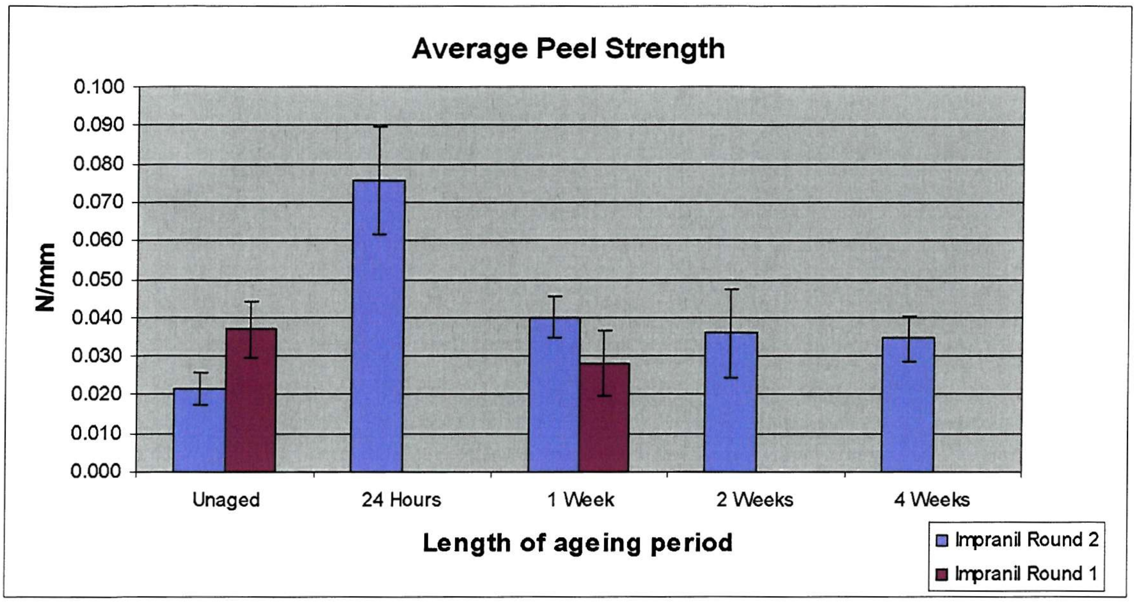
Section 5.3.5.1 suggested that at the end of Stage One there was slight evidence that the mass of adhesive applied/cm^2 affects the strength of the resulting bond. Figure 122 plots the mass of adhesive applied per square centimetre versus peel strength for all Impranil and Beva samples prepared in Round One and Round Two. It shows a small amount of continued evidence that the mass of adhesive applied influences bond strength. When considered alongside the data which relates adhesive mass to surface contraction it is clear that it would be important to apply no more than the suggested amount of adhesive in a conservation treatment in order to avoid greater than anticipated surface area shrinkage and duplicate bond strength results.



▲ **Figure 122: The mass of adhesive applied per square centimetre versus peel strength for all Impranil and Beva samples prepared in Round One and Round Two**

6.3.5.2 - Peel strength

The average peel strength determined at various stages in both Round One and Round Two are presented in Figure 123. Of primary importance for this work is the fact that with the exception of the bonds evaluated after 24 hours of ageing all of these averages fall within the range 0.014 N/mm – 0.071 N/mm, the range established in Round One which identifies a bond as still likely to be of an appropriate strength for the conservation of the *Globe*. Those evaluated after 24 hours of ageing fall just to the high end of this range at 0.076 N/mm. An additionally significant finding is that although Figure 123 shows that bond strength drops in the later stages of ageing it only does so by very small amounts. This could be an indication that the bond would have continued to be evaluated at an appropriate strength for at least a while longer had the duration of the ageing experiments continued.



▲ **Figure 123: The average peel strength for each sample set of Impranil and Beva bonds from Round One and Round Two. Each figure represents and average of six samples.**

However, while the appropriateness of the bond strength was not brought into question by this round of testing the behaviour of the bonds before and after ageing did appear to change, although within the limits of experimental error some changes are more significant than others. In Round One the average peel strength was reduced by a third after one week of ageing where as in Round Two the average peel strength almost doubled after the same amount of ageing and never dropped to its initial strength in the four weeks of testing carried out. An examination of the conditions in the lab shows that there was a significant fluctuation in ambient RH and smaller fluctuations in ambient temperatures during the testing (Table 29). However the fluctuations alone do not appear to explain the variations in bond strength behaviour. It is possible that the introduction of the naturally aged fabric with degraded adhesive still attached weakened the bond before ageing and strengthened it during the ageing process due to the reactivation of some of the degraded adhesive but this possibility was not proved or disproved in the testing presented here.

Table 29: The average ambient conditions in the TCC analytical laboratory for specific time periods during Round One and Round Two. For unaged samples the average represents the time between adhesive application and testing. For the aged samples the average represents the time between removal from the ageing oven and testing.

Sample Set	**%RH**	**Temperature in °C**
Unaged – Round One	30.8	21.8
Unaged – Round Two	43.9	22.3
Aged 24 Hours – Round Two	61.6	19.6
Aged 1 Week – Round One	44.4	23.0
Aged 1 Week – Round Two	55.2	19.7
Aged 2 Weeks – Round Two	60.1	19.8
Aged 4 Weeks – Round Two	37.6	21.0

6.3.5.3 - Stress rupture

The figures presented in Table 30 confirm the results of the peel tests. The bonds before ageing were weaker than those evaluated at 24 hours of ageing and again at four weeks of ageing. There was a pronounced increase in bond strength in the first 24 hours of ageing followed by a not quite so pronounced decrease in bond strength in the four weeks of ageing which followed.

Table 30: The viability of all stress rupture samples in Round Two and the average time to failure for all viable samples.

Ageing duration	**Number of viable samples**	**Number of samples failing in a day but primarily within the foam**	**Number of samples not failing within a day**	**Average time to failure in min:s** (range)
None	3	1	-	32:52 (16:40 - 44:42)
24 hours	4	-	-	242:41 (129:16 – 358:07)
4 weeks	2	2	-	55:00 (32:38 – 77:32)

6.3.5.4 - Location of failure

Table 31 details the location of failure for the tested bonds at each stage of ageing. In the peel tests the fabric and foam were consistently protected with bond failure always taking place at the interface between the Beva and the consolidated foam surface or within the Beva itself. In the stress rupture tests this was also the case in nine of the 12 samples with only the remaining three failing primarily or completely within the foam.

Table 31: The location of bond failure for peel and stress rupture samples evaluated at each stage of ageing. Those highlighted in red and purple failed in the locations identified as ideal (Section 6.3.2.4).

Possible Locations for Bond Failure During Bond Durability Testing	**No ageing**		**24 hours**		**One week**		**Two weeks**		**Four weeks**	
	Peel	**Stress rupture**	**Peel**	**Stress rupture**	**Peel**		**Peel**		**Peel**	**Stress rupture**
Between the fabric and the adjacent layer of consolidated foam or Beva	6	3								
Between the Beva and the consolidated foam										
Within the foam		1								1
Between the fabric and the Beva, and between the Beva and the consolidated foam			6	4	6		6		6	2
Between the fabric and adjacent layer of consolidated foam or Beva, and within the foam										
Between the fabric and the Beva, between the Beva and the consolidated foam, and within foam										1
Between the Beva and the consolidated foam, and within foam										

6.3.5.5 – Damage to fabric and foam

In all cases the damage done to fabric and foam during the peel tests is at or below 1, the level still considered appropriate for conservation standards (Figure 124).[134] Of particular interest is the fact that even when the bonds after 24 hours of ageing reached a strength which caused high levels of damage in samples prepared with the Lascaux and Beva combination they only caused acceptable levels of damage in this case. This meant only a scattering of fibres or pencil tip sized bits of foam were separated from their original locations during bond failure. Thus perhaps it is not just bond strength but also the materials involved in the bonding process which influence the type of eventual failure and damage.

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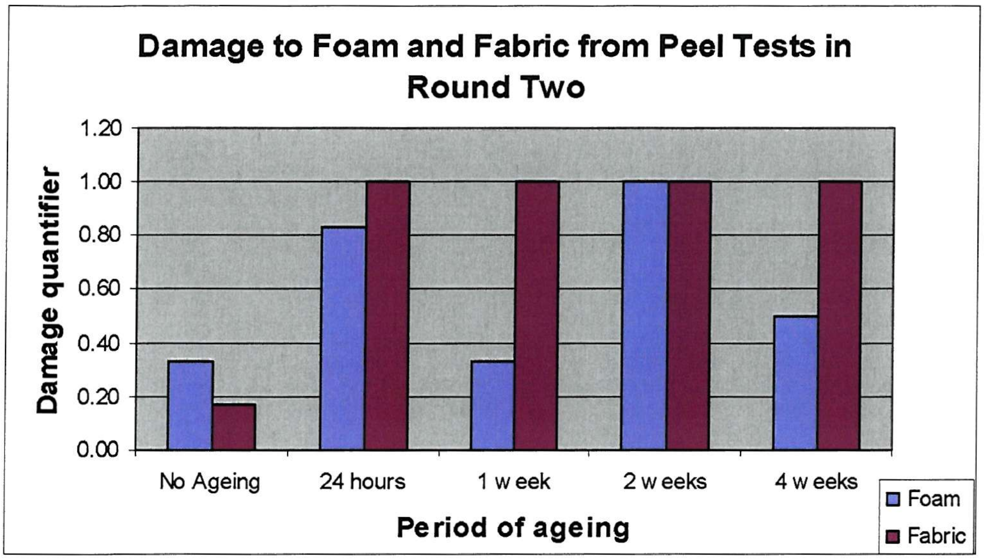
[134] Only the results of the peel tests are included here as the outcomes of Round One suggested that the stress rupture tests could produce anomalous data (Section 6.3.3).



▲ **Figure 124: The quantified damage done to fabric and foam at each stage of ageing evaluated in Round Two. No damage was quantified above 1.00 which was the limit of acceptable damage for conservation purposes.**

6.4 – Conclusion

Thus, in two rounds of experimentation, using quantitative methods of evaluation, the conservation possibility of using Lascaux alone to re-bond the original fabric to the original foam in the *Globe* was eliminated. The bond, as prepared in Round One of this stage of testing proved to be too weak to adequately support the fabric of the *Globe*. The investigated possibilities that employed Lascaux with Beva and Plextol with Beva were eliminated on the grounds of being too strong. The excessive strength of these bonds meant that the fabric bonded too well to the consolidated foam surface and when force was applied to the bond in order to induce failure the bond did not separate. Instead, the sample failed within the foam or at times between the Beva and the fabric. In both cases the failure caused significant irreversible damage to fabric and/or foam. The strength of the Impranil and Beva bonds before and after ageing was consistently quantified within the range of still apparently viable strengths established by the previously described obviously too weak and too strong bonds. At the same time, Impranil was found to cause the surface of the foam to contract to an extent that had potential to alter the profile of the *Globe* if the adhesive was applied during the conservation of the chair. However, two experimentally identified trends suggested that this quality of Impranil was not significant enough to eliminate it from consideration. First, dimensional changes caused by the drying/curing adhesive were shown to reduce as foam surface dimensions increased. Second, evidence suggested foam contraction could probably be suitably controlled by controlling the mass of adhesive applied to the foam surface. Thus Stage Two started with four possibilities and finally concluded with one which was determined to be worthy of serious consideration with respect to the conservation of the *Globe*: Impranil – 75% w/v brushed onto aged foam using the two stroke method; immediately after achieving apparent dryness Beva – 65 μm tacked to the adhesive coated surface at 85 ^{o}C for 15 seconds and then fabric adhered to the film at 85 ^{o}C for 90 seconds.

Chapter 7 – Conservation Recommendations and Directions for Further Research

The primary defined goal in this project was to identify an ideal conservation solution for the Globe and carry out testing which would help determine just how that ideal solution might actually be applied. With the determinations that leaving foam and adhesive in situ and re-adhering the original fabric to the original foam was ideal and a combination of Impranil and Beva could be used to achieve the re-adhesion in an apparently conservation appropriate way this primary goal was met. However, achieving this goal is not the only outcome of the research. As anticipated early on in this project (Section 1.7), the results and the process that produced them make it possible to make some recommendations with respect to the conservation of other foam upholstered objects. They also clearly identify some directions for further research which would be of benefit to other foam upholstered objects and the people trying to conserve them. The recommendations and directions are presented in the following pages.

7.1 – Conservation recommendations for the *Globe*

The end goal of this research was never the actual conservation of the *Globe*. The work was carried out with the specific object of the *Globe* and the conservation issues presented by it as the focus. It was based on a 'real life' problem and intended to find a 'real life' solution. However, because there was never any defined intention to actually conserve the *Globe* the safety of never actually having to carry out the designed work was always there. Just as a net below a trapeze artist encourages a practising performer to take slightly greater risks it was anticipated that searching for a solution without a deadline or even a sure possibility of having to apply it might provide the safety net required to try new things. Within this context every effort was made to be realistic but had a truly useable solution been found? If the possibility of applying the solution to the *Globe* became reality and the chair was still in a condition similar to that described in these pages would a recommendation be made to carry out the Impranil and Beva treatment in order to re-bond the original fabric to the original foam?

With one qualification the short answer to such a question is yes. The qualification is that the conclusion that Impranil will cause insignificant surface area contraction in foam pads the size of those used to upholster the *Globe* must be tested (Section 6.3.3). The long answer to the previous question knows that the bond strength of the Impranil and Beva solution has been quantified in two ways. It knows that the type of distortion the curing Impranil caused in the foam surface has been carefully measured. It knows that how the failing bond damaged the fabric and foam involved has been carefully documented. However, it admits that even with all the meticulous work that resulted in this knowledge questions still remain. While the strength of the bond is now known it is still not entirely clear whether the identified strength is appropriate for the proposed conservation purpose. After four weeks of accelerated ageing the bond was still in good condition but it is not clear that such a bond would really last for an acceptable number of years. While experimental design had been carefully thought out it had not been possible to test every variable related to actually applying the Impranil and Beva solution to the *Globe* and it is clear one of these untested issues could produce an unexpected result if the solution was applied.

7.1.1 – Is the bond produced by Impranil and Beva really of an appropriate strength?

To summarise what has been explained, in order to be appropriate for conservation purposes within the context of the *Globe*, an adhesive bond between fabric and foam needed to be strong enough to support the weight of the top cover fabric over a suitable period of time. Additionally it needed to be of a strength and quality such that when eventual failure took place it would not induce damage in the foam and/or fabric. In order to determine if the tested bonds met such criteria peel and stress rupture tests were used and they served as excellent means to compare bond strength within and across test sample sets. The results of these comparisons offer quite a few reasons to conclude that the bond produced by the specific combination of Impranil and Beva used in the tests meets the required criteria.

In 26 of the 30 peel tests carried out in Stage Two: Round Two, the peel strength was calculated at being within the acceptable range established in Stage Two: Round One. Being within this range did not guarantee that the bond was of an appropriate strength but it did suggest that no evidence had yet been found that it was too weak or too strong. Additionally, while four of the 30 bonds did fall outside of the range on the end that would suggest it was too strong none of them failed in a way that was inappropriate.

Thus while bond strength numbers might quantify them as too strong, the damage done to the sample in the peeling process did not.

In nine of the 12 stress rupture tests carried out the bond supported 627 g of weight for a period of time before failing in a way that only did acceptable damage to fabric and foam. In actuality a section of the *Globe* chair upholstery foam the same size as a stress rupture sample would only need to support approximately 3.5 g of fabric. Thus the 627 g used in testing is more than 170 times more mass than the bond would ultimately be required to support. If the sample can support such a large mass for less than a day it could certainly support a much smaller mass for much more time.

In all peel samples and all but three of the stress rupture samples the bond caused no damage or acceptable damage when bond failure was induced. If the bond was too strong it would have pulled many fibres from the fabric as it failed. Or it would have failed beneath the consolidant within the foam. Or it would have caused both types of damage as the Lascaux and Beva and Plextol and Beva bonds did in Stage Two: Round One when they were identified as too strong.

However, it is difficult to estimate a specific bond strength required for the *Globe* from the peel and stress rupture tests alone. The tests do provide a number related to the strength of a bond but that number reflects the properties of the adherends, the adhesives and the interactions between them as they are pulled apart. For instance, with the peel test, the force that is being used to pull the two adherends apart is being measured and recorded. However, the thickness of the adhesive layer, the angle at which the peel is taking place, the movement in the foam during the peel, the temperature and humidity at which the peel is carried out, the machine on which the peel is performed...affect the number that is eventually produced. This means that the exact same test carried out on two different machines or on the same machine under different conditions is likely to produce at least slightly different results. This variability makes it inappropriate to apply a direct correlation between the strength of a bond as measured in testing and the strength of a bond needed by the *Globe* (Defelsko n.d.; Packham 2005).[135]

Therefore, a specific bond strength value can not be assigned with respect to what would be appropriate for the *Globe* and it can therefore not be 100% determined that the Impranil and Beva bond is of an appropriate strength. Nonetheless, it can definitely be concluded that the Impranil and Beva bonds are not too weak. There is only a very a small amount of evidence that they may be too strong. The numerical values assigned to a few samples with respect to peel strength are part of this evidence. However, the type of damage done to these few samples when bond failure was induced shows that they are in fact of an appropriate strength. The other evidence which relates to the location of failure in a few stress rupture tests has been identified as anomalous (Section 6.3.3). It is therefore justifiable to conclude that the Impranil and Beva bond if applied to the *Globe* would provide at least short to medium term support with only a very slight risk of failing in an inappropriate manner.

7.1.2 – The question of longevity

Section 6.2.3 presented the primary reasons for selecting the ageing parameters used and indicated that by using such parameters it would be possible to correlate the results to at least five years of natural ageing and possibly more. Thus, the results of the ageing experiments which show that after four weeks of exposure at the previously described conditions the Impranil and Beva bond retains adequate strength and causes little damage to fabric or foam during rupture suggest that if applied during conservation today, the bond, foam and fabric would survive in good condition for at least five years. However, full acceptance of this conclusion and any effort to correlate the results to a

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[135] In order to work within the confines of the fact that the bond strength tests would provide excellent comparative data but not the data needed to translate the force used to separate the bonds into a figure which made it clear how much strength was needed, adhesives were identified which would produce bonds which were clearly too weak and clearly too strong for conservation purposes. Pritt Stick was identified as the adhesive which would definitely be too weak and Evo-Stik Carpet Adhesive, an adhesive which is marketed for adhering fabric to foam in home upholstery projects as well as for adhering carpets to floors, as the adhesive which would definitely be too strong and functional. Samples were prepared as outlined in Stage Two, Round One and subjected to peel and stress rupture tests but no accelerated ageing. They were to be analyzed along side the other four conservation bonds in order to provide a peel strength that was definitely too weak and another that was definitely too strong. In practice, the conservation adhesives established these boundaries on their own and these samples were not needed.

longer period of natural ageing requires acceptance of compromises and assumptions which had to be made in order to draw it.

First, the rates at which the degradative reactions described in Chapter 2 take place are uncertain. Therefore in order to equate periods of accelerated heat ageing to longer periods of natural ageing a general principle for the accelerated heat ageing of organic materials had to be used. It has been reported that a 5 to 10 °C rise in temperature doubles the rate at which a chemical reaction takes place (Michalski 2002). Thus a reaction which normally progresses at 20 °C would progress two to four times as fast at 30 °C, four to sixteen times as fast at 40 °C, eight to sixty-four times as fast at 50 °C, and so on. Using this principle it is possible to say that organic materials aged in the dark at 80 °C for four weeks can be considered representative of the same materials aged under natural conditions for anywhere from five to 300 years. The five year figure quoted above relies on the most conservative estimate that a 10 °C rise in temperature is required to double the rate of degradation. The 300 year figure relies on the most liberal estimate that only a 5 °C rise in temperature is required to double the rate of degradation. If an estimate half way between these two extremes is accepted and the degradation rate doubles with a 7.5 °C rise in temperature then the samples aged for four weeks at 80 °C are similar to 20 year old naturally aged samples. A definitive relationship can not be established but this range and happy medium can.

Secondly, at an even more fundamental level, in order to accept the time correlations above it must also be accepted that the accelerated ageing process produces results which mimic those of natural ageing. In order to accept this it is necessary once again to return to the process's differential influence on reaction rates but they will be considered from a slightly different perspective. It has also been reported that a 10 °C rise in temperature will in the same material double the rate of some degradative reactions, triple that of others and increase the rates of others by different amounts. The impact of this influence means that at only slightly increased temperatures various reactions progress at relatively similar rates but as the temperature rises the rates diverge more and more (Table 32). The result of this divergence is that the natural hierarchy of the primacy of reactions may be altered. At 20 °C primary and secondary reactions in a degradative process progress at a particular rate producing a particular degradative result. As the temperature is raised it is possible that the rate of a primary reaction may only double with a 10 °C rise in temperature but the rate of a secondary reaction may, for instance triple. Thus one day at 80 °C might be like 64 days for the primary reaction and 729 days for the secondary reaction. This would move the degradative affects of the secondary reaction much further along than those of the primary reaction and result in a prediction of a level or type of degradation that may actually never occur (Berger & Zeliger 1984; Howells et al 1984; Museums and Galleries Commission 1992).

Table 32: The influence each 10 °C rise in temperature will have on the rate of a reaction depending on whether the temperature rise doubles, triples or otherwise affects the rate.

Temperature	Rate of reaction x 2	Rate of reaction x 2.5	Rate of reaction x 3	Rate of reaction x 3.5
20 °C	1	1	1	1
30 °C	2	2.5	3	3.5
40 °C	4	6.3	9	12.3
50 °C	8	15.6	27	42.9
60 °C	16	39.1	81	150.1
70 °C	32	97.6	243	525.2
80 °C	64	244.0	729	1838.3

In order to mitigate the affects of this disparity in reaction rates it is advised to keep temperatures as low as possible in the heat ageing process with some arguing such ageing should only be carried out at room temperature (Berger & Zeliger 1984; Down 1984 & 1995; Howells et al 1984). However, the time scale for most projects is limited and in such cases a compromise between minimum temperature and maximum ageing affects must be reached. The selection of 80 °C for four weeks is the end result of the compromise for this project and reflects an effort to balance ageing effects with an ability to correlate the results to a reasonable length of natural ageing.

Thus, if these two assumptions and compromises are accepted as valid then it is clear that the Impranil and Beva bond tested in the ageing process will last for somewhere between five and 300 years if applied to the *Globe* today with an estimate of 20 years being the happy medium between the two. If the assumptions and compromises are not accepted it is still clear that while there is an initial spike and then drop in bond strength, over the majority of the ageing process very little bond strength was lost (Section 6.3.5.2). It is clear that very little damage is done to fabric and foam during bond rupture after any stage in the ageing process (Section 6.3.2 and 6.3.5). It is clear that the ageing conditions used were fairly aggressive suggesting the results are less apt to down play what might happen (Packham 2005). It is clear that while not perfect, accelerated ageing is a well accepted way to predict what might happen and it is clear that what might happen is an Impranil and Beva bond in the *Globe* will survive 20 years or more of natural ageing.

7.1.3 – Other unknowns and complicating issues

Issues of bond strength and longevity formed the primary focus of this investigation however the uncertainties surrounding them are not the only ones that need to be clarified. There are ethical issues as well as practical ones which have been raised (Chapters 1 and 3) and these issues need to be re-visited before the implications of a recommendation to carry out the proposed treatment can be fully understood.

The solution is not fully reversible. Once applied the Impranil would not be able to be removed from the foam. Once cut original stitching could never be made original again. If the <u>do nothing</u>, <u>slow degradation</u> or <u>support without intervention</u> method had been selected as the method of choice the original stitching would be able to be preserved and no irreversible additions would be made. However, although documents like the AIC (1994) and AICCM (2002) guidelines for practice still call for reversible treatments, in today's conservation culture the reversibility of treatments is generally considered an ideal goal but not an absolute requirement (Eastop 2006; ICOM 2006; Rivers & Umney 2003; Viñas 2005). It has been argued that in order to simultaneously conserve the materials used in the original construction of the *Globe*, the design and production processes used to turn an idea into a physical object, and the original shape of the chair a non-reversible solution was required (Chapter 3). The process of identifying the specifics of that solution has revealed that although the solution is indeed non-reversible it does exist on a practical as well as theoretical level. Its application to the *Globe* will permanently alter the chair but in a way that will preserve maximum knowledge for the current and future users of the chair.

There is also the possibility that applying the identified solution to the *Globe* will make it harder to conserve in years to come. It has been suggested that aged Beva is not easily removed from textile substrates.[136] The material is well used in textile conservation. It was thoroughly tested early in its development and its use has been reviewed.[137] However, aged adhesives do develop unexpected behaviours. It is possible that the Beva would cross-link or otherwise age in a way that would eventually make it difficult to remove it from the fabric surface. It is also possible that while the described work did not reveal such evidence the adhesives and heat applied to the foam during the conservation process might eventually cause the foam to swell much like what has apparently happened in the *Ball* at the MMFA (Section 1.6). Should either of these possibilities become reality both adhesive encrusted fabric and swollen foam would make further conservation of the *Globe* much more difficult.

It was explained in Section 1.3.3 that it appears that when the *Globe* top cover fabric was initially applied to the foam padding it was slightly tensioned during the process. If this is the case some tension would have to be reapplied in the conservation process in order to make the fabric rejoin the foam in its original alignment. The previously described experimental work did not include variables of tensioned and untensioned fabric. Therefore the work provides no information as to whether or not some tension would affect initial and/or long-term bond strength. It is possible that if the top cover was slightly tensioned during adhesion the process would add a factor to the bond that would induce failure at an earlier stage and/or in an undesirable location.

Another possible source of untested strain is the fact that if the Impranil and Beva bond was applied *in situ* in the *Globe* the fabric would have to be adhered to a concave surface. The testing process only used flat surfaces. Perhaps the altered geometry would make no difference to the bond but then again perhaps it would. At the very least a heat source which could accommodate the concave surface would need to be found before the re-adhesion could take place.

Finally, as was explained in the previous section, the length of time the accelerated ageing tests suggest an Impranil and Beva bond would last in the *Globe* is a bit

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[136] Personal conversation with Marion Kite, Head of Textile Conservation, V & A, 3 July 2007.

[137] See Beerkens 2002, Berger & Zeliger 1984, Butzer 2002, Doyal 1996, Karsten & Kerr 2003, Katz 1985, Kessler 2004, Kronthal et al 2003, Nieuwenhuizen 1998; Nuttgens & Tinker 2000 and Peacock 1984 for published examples of the testing and use of Beva 371 in the field of conservation. This comment is also based on personal experience at the TCC.

ambiguous. However, there is no doubt that at some point the foam to which the adhesives would be applied will degrade to a completely non-functional and even unrecognizable state. Therefore the proposed solution is definitely not permanent. If such a change is 300 years in the future, as a liberal interpretation of the ageing results would suggest, then the point is of no concern to the argument here. A conservation treatment that survives for 300 years would out live many objects! However, knowledge from within and outside of the conservation profession points to a date much closer to the present day when such degradation will take place. At such a point the object would need to be re-conserved if the original profile of the chair was to be retained.

7.1.4 – So why should the treatment move forward?

If it has not been obvious to this point, the clarification of all of the above uncertainties should now make it clear why the actual application of the treatment to the *Globe* might be argued against. While every effort has been expended to discover if the solution will work and it appears it will there is no guarantee of the fact. If it does not work it could cause irreversible damage to fabric and/or foam. Even if it does not cause such damage the treatment is not fully reversible in the first place and as time passes it may become even less so. There are a few untested aspects of the application process which offer further unknowns and it is known that the solution will not last forever. The process will involve the introduction of new adhesives applied in a different manner to the methods originally used in the chair's construction. It will require the release of original stitching and most likely small areas of still secure original adhesive bonds. However, even with all these uncertainties and shortcomings, the solution offers the best possibility for returning the profile of the chair to its original state while minimizing alterations to the original construction of the chair. The solution has been carefully tested. It appears it will work. If offered the opportunity to put it to use in the *Globe* the opportunity should be taken.

It is possible that this rationale in some ways sounds cavalier. Perhaps a treatment should never go forward that has been shown in experimentation to have possibilities for failure. On the other hand, if a well tested treatment possibility generally appears that it will be successful there is no way to know how it will truly behave unless applied to an actual object. This project has been carried out with one specific object in mind. All efforts have focused on whether or not the fabric and the foam in the *Globe* not *Balls* or the general class of foam upholstered objects could be re-adhered. It appears a solution has been found. Only in trying it will the truth of the matter be told. Perhaps failure of the solution will be the result and an originally less desirable method of conservation will have to be applied. However, in its failure the more theoretically desirable solution will have shown itself not to be so ideal and the benefits of the originally less theoretically desirable solution will become clearer.

In a world where the conservation of foam upholstered furniture had a long history of treatments involving the re-adhesion of stable fabric to relatively stable foam, perhaps moving forward with a treatment which involves risks like those described above would be inappropriate. Perhaps there would be a large enough body of knowledge to make it clear whether the solution would ultimately be realistic. Perhaps there would not have even been a need for the project because general protocols for such conservation issues would be well established. The protocols might require small amounts of experimentation in order to identify the exact specifics of an acceptable treatment but the basic approach would be there. However, such a large extensive body of knowledge does not exist. Moving forward with the apparently reasonable treatment would help with the process of establishing this body of knowledge. Foam upholstered furniture in museums is a problem today and it will continue to be so. Conservation solutions need to be tested in order to develop a clearer picture of what can be done for these objects.

One of the great benefits of testing this solution is that if it does not work and the bond fails in the foam as a few of the stress rupture tests did there is a back up solution. The foam could be removed from the chair. The Beva film and any attached Impranil and foam residue could be removed from the fabric. New foam pads could be supplied. If polyether polyurethane pads were desired a couple sources for such pads have been identified (Section 3.1.5). If a conservation grade foam was more preferable sources of such foam are readily available. No matter what foam was selected the challenge of selecting and devising a method for securing the original fabric to the selected foam would need to be tackled but as this work has shown there are ways such a task could be handled. If the bond failed inappropriately the situation could be rectified.

Thus, an ideal solution for the *Globe* has been identified. A way to apply the solution has been determined and tested. Taking some very calculated risks and applying the solution to the *Globe* could not only benefit the *Globe* but also the process of developing a useful body of knowledge with respect to what can be done with objects similar to it. And, if all else fails there is a back up plan. With this there is no doubt that barring further significant degradation before application the original fabric should be re-adhered to the original foam in the *Globe* using the described Impranil and Beva combination.

7.2 – Conservation recommendations for other *Balls*

The next obvious question to consider is should the Impranil and Beva solution be applied to other *Balls*? As Chapter 1 makes clear, no two *Balls* examined in person or through photos during this project are exactly the same. Some, like the Sotheby's *Ball* and the VDM's MSK-1001-2 exhibit sagging in the top cover fabric which suggests that they might currently be in a condition very similar to that of the *Globe*. Others, like the MMFA's *Ball*, are clearly in a very different condition but also in need of upholstery conservation before being able to function as display items and still others, like the VDM's MSK-1001-1 and SSK-1002, were in no need of upholstery conservation at the time that they were examined for this project. For each of these categories there is now a conservation recommendation that can be made.

The first is for chairs which exhibit sagging top covers and give the initial impression that they are in a condition very similar to that seen in the *Globe*. If a closer physical examination showed that it was apparently adhesive failure and not crumbling foam that was the cause of the separated top cover it would be recommended that a sample of the obverse surface of the shell upholstery pads and the no longer functional adhesive be removed from the chair. If FTIR spectra of the samples showed them to be of a similar composition and in a condition very similar to the samples removed from the *Globe* and the 2CM pads closer physical examination of the surface of the fabric and foam which would need to be re-adhered would be recommended. If such an examination found that the surfaces were in a condition similar to that found on the samples used in the testing process of Stage Two: Round Two it would be reasonable to try applying the recommended solution to the examined chair.[138] If however obvious condition differences were found at any stage in the examination process more details would be needed before the direct applicability of the solution presented here could be assessed.

For chairs in conditions like that presented by the *Ball* at the MMFA a simple direct application of the solution is obviously not possible. In this chair the fabric is now actually quite securely fastened to the foam. The foam itself has expanded. Right now the surfaces do not need to be re-adhered but in order to re-establish the profile in the

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[138] It is strongly recommended that if such a chair is found treatment not be carried out without further consultation with the author. Every effort has been made to fully describe the process and how it was tested but an effort to replicate exact results from this text alone is not likely to be successful.

chair what probably needs to happen is the fabric needs to be separated from the foam. The foam probably needs to be cut away or replaced and then the surfaces would need to be re-adhered. If such an approach were taken then what is likely to be applicable however is that if the foam is polyether polyurethane foam and the fabric is 100% wool Impranil and Beva would probably offer a road to a solution.

This can be suggested because initial stages of testing for this project were carried out on polyether polyurethane foam and 100% wool fabric which had no adhesive residue. The majority of the work was carried out with the same materials but using a surface of the foam that had adhesive residue. The final stages of testing were carried out with the same foam and adhesive residue surface and a different 100% wool fabric this time with an adhesive residue. In all cases bonds with reasonable to more than reasonable strength were able to be produced. Thus it does not appear that the adhesive residue is integral to the process of establishing a good bond between the two surfaces. It is hypothesized that this is because the bonding actually took place despite the presence of the degraded adhesive residue rather than because of it. When the residue was present the adhesives bonded to the exposed fabric and foam around it. When it was not the adhesive simply bonded to the foam or fabric surface. In both cases the Impranil and Beva were then left to bond to each other. Thus presumably as long as the Impranil was applied to enough of a polyether polyurethane foam surface and the Beva was applied to enough of a wool surface a reasonable bond between the two would be able to be established. If the MMFA's *Ball* or any other *Ball* eventually presented two such surfaces needing to be adhered Impranil and Beva would be a good place to begin the testing process.

For *Balls* exhibiting no apparent need for conservation at the moment probably the most important result of the work is the development of evidence that there is still functional life in the *Globe* even though the sagging top cover fabric may lead one to draw the opposite conclusion. Therefore an assumption that nothing can be done once initial signs of degradation appear in a currently apparently stable *Ball* would be inappropriate. It is certainly possible that it will transpire that the problem presented is different than that described here and maybe nothing will be able to be done. On the other hand, maybe the problem will be the same in which case an intrusion at the onset of the problem would offer the possibility of maintaining the chair in a condition appropriate for display. At this point in time such maintenance is only a possibility because there is the problem that failure will probably begin in an area which can not be accessed without releasing some of the original bond, a less than ideal approach.[139] Additionally, repair of a small area of failure is likely to have to be followed by repair of another small area of failure and so on and so on. These issues raise a point for further research which will be discussed in Section 7.5 and until such research arrives at a successful conclusion an earlier intrusion into a *Ball* degrading like the *Globe* may not be possible.

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[139] See the description of VDM – SSK-1002 in Section 1.6

7.3 – Conservation recommendations for other foam upholstered furniture

Just as all *Balls* are not like the *Globe* all foam upholstered furniture is not like a *Ball*. Objects are upholstered with different fabrics and different foams. Some were upholstered using adhesives and some were not. Those that do contain adhesives do not all contain the same adhesive used in the *Globe*. Even so, it is possible to take the knowledge gained in this work and use it to make some general recommendations with respect to the conservation of foam upholstered furniture.

The first recommendation is that the conservation of foam upholstered furniture begins with museum collecting policies and procedures. The better the condition in which these pieces are acquired the longer they are likely to survive in a 'useable' condition. If upon arrival they are provided with proper support in any area that is clearly under stress simply because of the design or the materials used in the chair the object will have better potential for survival. If they are stored in dark, oxygen free and/or cool storage facilities their survival is likely to be lengthened. However, because it is clear that foam upholstered furniture is likely to deteriorate at a faster rate than many pieces from previous centuries such objects should not be collected with an expectation that they will fill a space in a long-term study collection. This would be particularly true if the study collection was stored in a 'typical' museum facility and no scope for the care of the foam upholstered pieces in it through interventive conservation was provided. Such pieces should be collected with shorter term goals in mind. Finally, such pieces should be collected by institutions with de-accessioning policies in place because they will deteriorate, they will need conservation to maintain them in a 'useable' condition and they may reach a stage when conservation can no longer maintain them in a condition which makes them worthy of museum space. Then they will either need to take up space they no longer deserve, need to be restored or need to be de-accessioned.

Once it is clear an object has begun to degrade, as with the *Balls* above, it is strongly suggested that with a foam upholstered object an earlier intervention is probably better than a later one. If a chair has degraded in a way that exposes foam to a more direct flow of air earlier closure of that gap through which the foam is now exposed is likely to be better than a later one. It is likely to slow further degradation of the foam and in so doing prolong the life of the object. If a crumbling foam surface can be stabilized and consolidated it may be found that the remaining foam is still quite functional. If a top cover is losing support due to the degradation of an understructure an earlier repair of the understructure is likely to offer better protection for the fabric. For the *Egg* chair at the Museum of Fine Arts, Boston (Figure 5, Page 9) and others like it, an earlier rather than later restoration of its profile is probably preferable. If the profile is restored now, in the early stages of its degradation, the work might be able to be accomplished with much less work than if it was left until the original profile of the chair was no longer obvious. In fact, perhaps the conservation of foam upholstered objects needs to be looked at more like a maintenance project where objects are regularly touched up rather than brought in for major overhauls.

Once a project is begun, chemical identification of the materials involved would be an important first step. It is important in terms of establishing a body of knowledge with respect to what materials were used for what purposes and by whom. It is important in terms of establishing a body of knowledge with respect to how the materials are degrading. It is important in terms of establishing a conservation plan for the materials. If the foam needs to be consolidated or something needs to be re-bonded to it knowing the chemical and physical structure of the materials will help with the selection of adhesive and/or consolidants. If materials need to be found to carry out testing, proper identification of the original materials will help with the process of locating surrogates of both an appropriate physical and chemical nature. For these purposes a multitude of samples is not likely to be necessary but consultation with the individual who will be carrying out the work is and the consultation should take place before samples are removed.

With respect to actual techniques for conservation several suggestions can be made. The one which is made with the most conviction is that if a foam and a fabric surface need to be re-bonded during a conservation project the two-step solution of consolidating a foam surface and then adhering the fabric to that consolidated surface with a different adhesive should be thoroughly investigated. The approach begins by strengthening and protecting a foam surface. It then adheres fabric to this protected surface with a second adhesive. If the adhesives used to consolidate the foam and adhere the fabric produce a bond that can be engineered to fail at their interface then both surfaces are protected to the maximum extent. The foam is protected by the consolidant which holds it in place as the bond fails. The fabric pulls away with a layer of adhesive on its reverse. This adhesive layer can then be removed in a controlled fashion. As described, initially it was thought an adhesive would be applied to the foam and that adhesive would then be used to secure the fabric to the foam. However no such one-step solution was found. The resultant two-step method was developed due to the fact that the initial plan did not prove to be feasible. In the end however it is clear that it is a better solution. It does more to protect the original materials involved than a one-step solution seems likely to ever be able to do. In any re-adhesion it is strongly recommended that such a two-step solution be investigated.

The other recommendations are as follows. In most cases water-based adhesives are probably the safest when treating foam upholstery materials but the likely affects of both water and other organic solvents should always be investigated prior to treatment. Again in most cases solvent reactivation of any adhesive should be avoided due to the unpredictability of the interactions between aged foams and solvents. If an adhesive or a consolidant needs to be applied brushing is an acceptable technique for generally stable surfaces. However if penetration of the adhesive/consolidant needs to be deeper than the surface another technique would need to be investigated. Such would also be the case if the foam or other degraded plastic was too fragile to withstand brushing. Finally, if an object presents a degraded but generally secure surface, like the degraded adhesive, it may be possible to conserve the object without scraping away the degraded evidence. The privately owned chair in Figure 10, Page 11 may be a specific example of this. The chair appears that it was originally upholstered by foam laminating the top cover fabric to the foam understructure. Whatever it was that originally secured the two surfaces is no longer functional in most areas but it is not crumbling off the chair. If the residue behaves like the polychloroprene based adhesive did it would not need to be scraped away. An adhesive could be applied right over it sealing the evidence in place. Another adhesive could then be applied to the sealed surface to re-adhere the fabric to the surface.

Finally, the work raised two points which are most accurately presented as developing personal preferences rather than recommendations. The first is that when treating synthetic objects the use of synthetic materials seems to be a more sympathetic approach. The other is that if an object is being treated and the foam in the object will be covered by fabric in its final presentation the visual qualities of the foam like sheen and colour are not of primary importance. If they can be preserved it is a bonus but much like reversibility it is not a requirement.

7.4 – Directions for further research related to the experimental portions of this work

Due to the limits of time and materials there were many compromises which had to be made in designing and carrying out this work. Without the luxury of endless time and endless resources such compromises are unavoidable. Even with such luxuries the limits available knowledge put on decisions which must be made at a particular point in time mean that with hindsight many things could be better designed the second time around. Using knowledge gained as the described work developed and the benefit of hindsight, six projects have been identified which would make it possible to continue the original project by building on the concluded work in several ways. Three projects are related to the materials testing processes which were used and the other three are related to further investigating the use of a polyurethane consolidant and a polyvinyl acetate adhesive to bond polyether polyurethane foam and 100% wool fabric.

7.4.1 – Materials testing – fine tuning peel test methods

The peel test, as described in Section 6.2.2.1, includes a number of modifications on what would be described as a 'typical' test involving two flexible adherends. In such a 'typical' test a sample of each adherend is prepared with a 150 mm x 25 mm surface ready for adhesion. These surfaces are then joined leaving 25 mm of each adherend unadhered at one end. The unadhered ends are clamped into the test instrument and the sample is peeled apart. This was the intended approach for the peel samples carried out in this work but several obstacles presented themselves when trying to apply it. In overcoming these obstacles a method alteration was developed that might be useful to others carrying out materials testing with requirements similar to that described here.[140] However further adaptations of the altered method have the potential to make the system even more useful.

The first obstacle which presented itself and began the process of system modifications was the fact that the Instron® grips into which the unadhered ends of the foam and fabric samples described in Section 6.2.2.1 had to be inserted only opened to a width of

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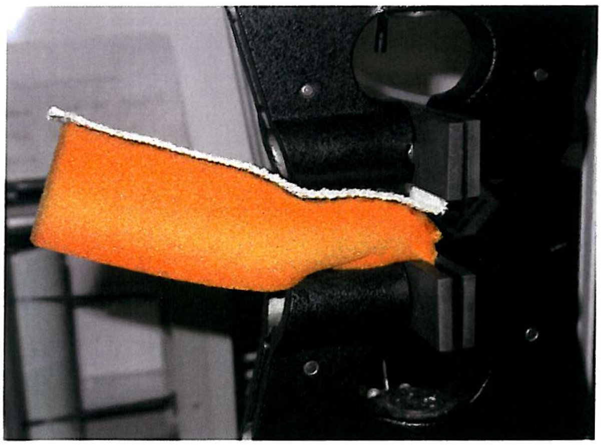
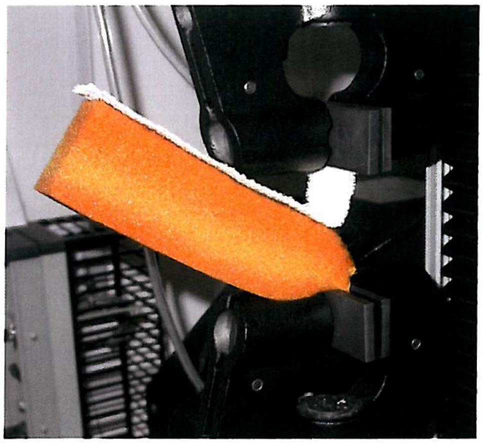
[140] Personal conversation with Dr. Paul Garside, Postdoctoral Research Fellow, TCC, University of Southampton

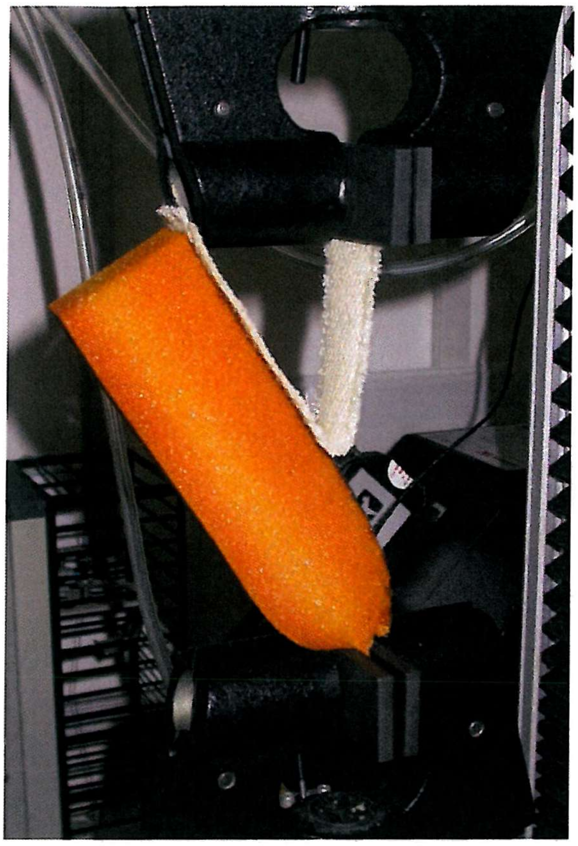
6 mm. This meant that a 40 mm thick sample of foam needed to be compressed to less than 6 mm. This process was achieved by placing a thin metal plate on either side of the foam, bringing them together, sliding the sandwich into the lower grips of the Instron® and then sliding the metal plates out of the grips leaving the foam in place. With this process achieved the Instron® crosshead holding the upper set of grips had to be brought within 25 mm of the other set of grips in order to make it possible to insert the unadhered fabric tail into the upper grips. This could be achieved but in order to do so the foam sample had to be compressed between the two sets of grips (Figure 125). The action of compressing the foam caused it to push up on the upper grips which in turn pushed up on the load cell and crosshead disrupting the calibration of the machine. As a peel began the foam continued to push up on the grips, load cell and crosshead and only after the upper set of grips cleared a height of about 125 mm and the foam could no longer reach the upper grips were the values recorded by the Instron® no longer altered by this affect (Figures 126 & 127). Additionally, the combination of the way the foam expanded as it emerged from the lower grips and pulled on the fabric during the peel process meant that the resultant angle of peel was not actually the 180 degrees required for the test (Figure 128).



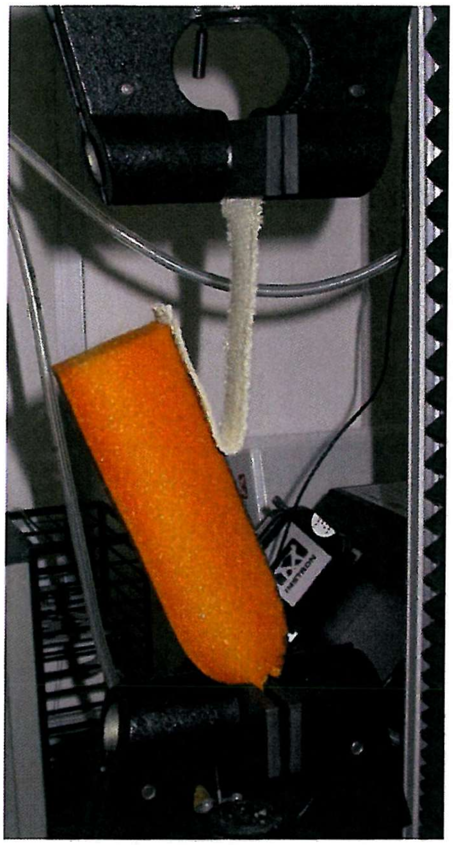
▲ Figure 125: A sample mounted in the Instron® at the start of a peel test. Note the compression of the foam in the lower set of grips as well as between the lower and upper grips. (Photo – J. Wickens)



▲ Figure 126: A sample part way into a peel test. Note the foam pushing up on the upper set of grips which in turn pushes up on the load cell and crosshead disrupting the calibration of the Instron®. (Photo – J. Wickens)

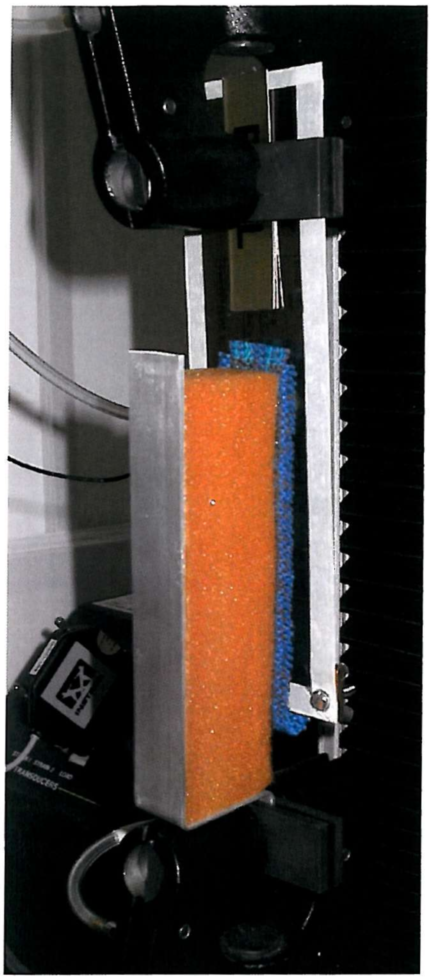


▲ Figure 127: A sample not quite half way through a peel test. Note the foam is still pushing up on the upper set of grips at the point where the grips are just about to clear the rising foam. (Photo – J. Wickens)

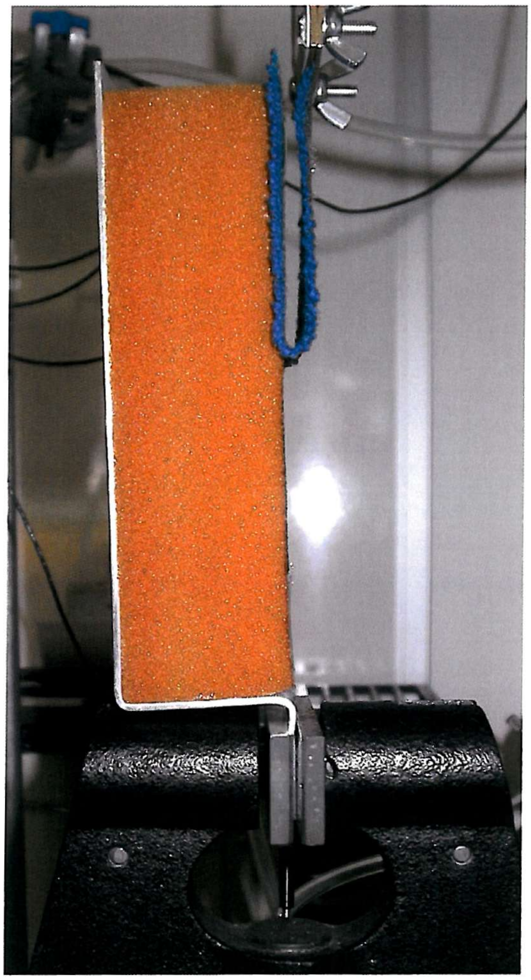


▲ Figure 128: A sample now more than half way through a peel test. Note the angle of peel is far from 180 degrees due to both the expanding foam as it emerges from the lower grips and the pull of the foam on the fabric during the peel. (Photo – J. Wickens)

In order to overcome these challenges the following modifications to the test system were developed. An aluminium bracket was prepared onto which the foam portion of the sample could be adhered. This bracket could then be mounted in the lower grips of the Instron® placing the foam/fabric interface at the centre of the grip. Then a second attachment which was slightly longer than the height of the foam was clamped in the upper grips. It had a hinge mounted on its lower edge and the fabric tail of the sample was gripped in this hinge (Figure 129). These adjustments made it possible to secure the sample in the Instron® without having it push up on the upper grips and peel it apart at an angle of nearly 180 degrees (Figure 130). Exactly how a peel was achieved with these modifications has been described in Section 6.2.2.1.

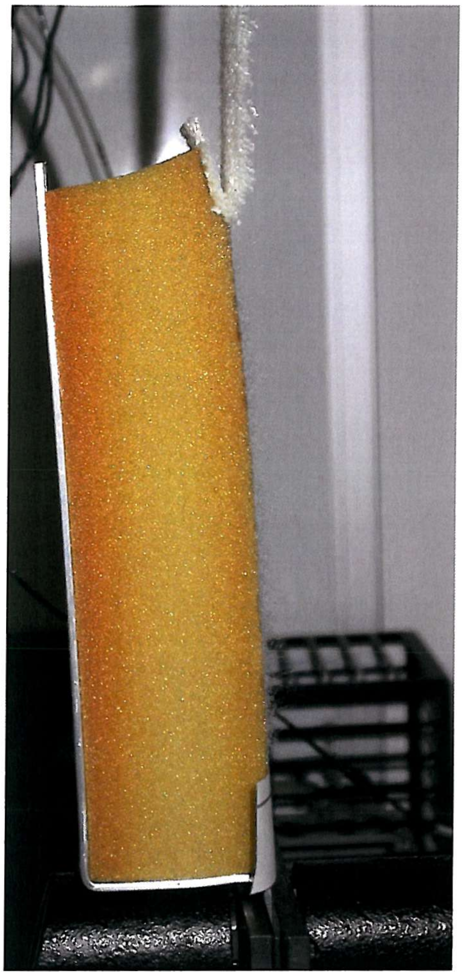


▲ Figure 129: A sample at the start of a peel which has been mounted using the described modifications. Note the edge of the hinge mounted on the bottom edge of the upper extension is just visible at the bottom right corner of the plate. (Photo – J. Wickens)



▲ Figure 130: A sample just over half way through a peel using the new mounting system. Note the peel angle is now much closer to 180 degrees, the foam surface is in line with the centre of the lower grips and the attachment pulling up on the fabric is just about to move out of the top of the photo. (Photo – J. Wickens)

As carried out the solution was not perfect. The brackets used to secure the sample in the Instron® were not precisely square. Therefore there were slight variations in how the sample was aligned once it was mounted in the machine. Although mounted in a firm bracket and pulled with an attachment in which there was no apparent movement, there was some movement in the foam during the peel process (Figure 131). The depth of the brackets was not precise enough nor was the technique used to adhere the samples to the brackets. The result was that the interface of the foam and fabric did not always end up just above the centre of the lower grips.



▲ Figure 131: A sample nearing completion of a peel. Note that the upper surface of the foam has been stretched out of alignment. (Photo – J. Wickens)

For the purpose of the work done in this project the solution was sufficient. It produced consistent numbers which could reasonably be compared within and across sample sets. However, further research related to fine tuning these modifications could be quite useful. The system would be improved by making sure all bends in the brackets were perfect 90 degree bends and the surfaces of the brackets were all in parallel planes. Additionally, if the brackets were prepared with a very, very precise depth measurement and the sample mounting technique was perfected so the face of the peel was located just at the centre of the lower grips every time the system would be further improved. Finally, an additional bend in the mount at the top of it which would hold the top surface of the foam block in place during the peel could potentially hold the foam steadier during the peel process. Each modification would make tests results more precise and therefore more reproducible making them more available for comparison.[141]

7.4.2 – Materials testing – adjusting stress rupture test methods

Early on in this project it was anticipated that by running stress rupture tests alongside peel tests a low-tech method of bond strength evaluation could be developed. As carried out the tests did not provide enough viable data and exhibited some anomalies with respect to location of failure which made it unreasonable to try and establish specific correlations between stress rupture results and peel results. However a test like the stress rupture test would be infinitely useful for conservators trying to determine if a bond was an appropriate strength without the high-tech tool of an Instron® or another manufacturer's equivalent. Therefore investigations designed to develop modifications which will improve the test have been identified as a useful direction for further research.

As previously explained (Section 6.2.2.2) the version of a stress rupture test used in this project was designed so that a bond of apparently useful strength or one that was too weak would fail in a day and a bond which was definitely too strong would not. A day was selected as the marker of the end of a test in order to make it convenient and simple for a conservator to use. A weight of 627 g was experimentally identified as the amount of weight needed to engineer bond failure within the limits just described. In practice, the test functioned much as it was designed. The Impranil and Beva and Lascaux only bonds failed within a day and they were eventually determined to be either of an apparently useful strength or too weak. The majority of the Lascaux and Beva and Plextol and Beva bonds endured well beyond the test end marker and these bonds were eventually identified as being much too strong. However, during the stress rupture tests some of the bonds caused types of damage during failure all other testing gave no indication they would. These unexpected results were seen to be evidence of two possibilities. Either the bonds identified as apparently reasonable by peel tests and the

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[141] Many, many, many thanks to Mike Halliwell, Robert Smith and Kathryn Gill who spent valuable weekend and evening hours fashioning the requested mounts.

majority of stress rupture tests were in fact too strong or the specific design of the stress rupture test needed to be adjusted to produce more realistic and thus repeatable results.

Work carried out to determine whether one of the previous conclusions is correct or in fact there is another reason followed by work to accumulate enough data to begin correlating the results of peel and stress rupture tests would be an excellent next step. It is suggested that such work begin by considering the fact that the 627 g weight used in testing was actually more than 170 times more weight than a section of *Globe* upholstery foam would ever need to support. Perhaps the decision to bring the test to ultimate failure in a day had identified an amount of weight which when used put unrealistic and unrepresentative stresses on the samples. If so, perhaps development of a test method which used less weight over a longer period of time would produce the type of results needed to make it useful to those for whom the test development was originally intended.

7.4.3 – Materials testing – preparation of samples for natural ageing

The pros and cons of the use of accelerated ageing as a method of predicting the long term behaviour of materials have been fully presented earlier in this chapter. It is highly likely that the results of the processes used in this work are not completely representative of natural ageing. There is little historical precedence to provide information regarding how Impranil and Beva applied to polyether polyurethane foam and wool will behave in the years following an application like that suggested here. Such is also true for the other adhesive combinations tested alongside Impranil and Beva. For this reason, a set of samples prepared with the Impranil and Beva combination, and others if material supplies allowed, which could be left to naturally age could be put to good use. Depending on the number of samples prepared which would be dependent on the amount of sample material still available, they could be peeled apart at certain yearly intervals to provide comparative data with respect to the results gathered from samples which were aged under accelerated conditions. It might also be possible to monitor the degradation of the foam in the samples alongside samples to which no adhesive was applied and samples which have had adhesive applied and been subjected to accelerated ageing. Both of these possibilities and any others which could be identified would contribute to the development of a body of knowledge with respect to the long term behaviour of conservation treatments for foam upholstered furniture – a body of knowledge which does not exist today.

7.4.4 – Improving the consolidant/adhesive combination

The identification of a polyurethane consolidant as one element of an apparently successful solution for the *Globe* is perhaps not a surprise based on the other work that has been carried out in the conservation field regarding the consolidation of polyether polyurethane foam with Impranil (Rava et al 2004; van Oosten 2004; Winkelmeyer 2002). However, polyurethanes are not generally used in conservation. Further work which determined whether or not polyurethanes really offer the best solution for polyurethane foam objects would guide future projects involving such materials. Such work might include an investigation into what other polyurethanes are available, which ones meet or come closest to meeting established conservation standards, and what the ethical implications of their use would be.

This would be the first step in a project which could have at least two follow on investigations. They are presented here in a particular order but it might be found that investigations in the reverse order or simultaneously might be more appropriate. The first would be that if other useful polyurethanes could be identified how they behave in combination with Beva Film and other polyvinyl acetate adhesive films might be investigated. Impranil and Beva have been shown to work for the *Globe* but perhaps there is a different combination of a polyurethane consolidant and a polyvinyl acetate adhesive which would be even more suitable for use with polyether polyurethane foam and wool fabric objects.

The second follow on would build on van Oosten's (2004) pilot project which compared the degradation of unimpregnated polyether polyurethane foam, polyether polyurethane foam impregnated with Impranil and Plextol (two of the adhesive/consolidants used in this work), and polyether polyurethane foam impregnated with Impranil and the anti-oxidant vitamin E. The results of this project show that while impregnation with Impranil or Plextol alone does not slow the degradation of polyether polyurethane foam impregnation with an Impranil and vitamin E does. At this stage the work is far from definitive but it offers an interesting possibility for the conservation of a piece like the *Globe*. Research that investigated the inclusion of antioxidants in a surface consolidation process like that used in the work presented in this document might find that such an inclusion would slow the eventual degradation of the foam. However, it might also affect the adhesion capabilities of the consolidant with respect to the adhesion to foam and/or polyvinyl acetate film and this possibility would need to be considered as well.

7.5 – Directions for further research related to other methods of foam upholstered furniture conservation

Because of the nature of the conservation challenges exhibited by the *Globe* and the direction of the research undertaken to find answers for those challenges there were many problems related to the greater class of foam upholstered furniture which were not investigated during this project. This is not because the problems presented poor avenues for investigation but simply because they were not directly relevant to the project as it was undertaken. In considering the possibilities for the *Globe* possible starting points for some of these avenues were uncovered, opinions related to them were shared and possible road blocks to the development of successful conservation techniques were identified.

Perhaps the most glaring challenge that this research does not offer much of a solution for is that of degrading crumbling foam. Such foam has generally already caused significant profile loss in objects. It is too fragile for adhesives to be applied with a brush. It is hard to imagine it would ever be able to support the weight of fabric like the foam in the *Globe*. It has been explained that historically the most common approach to the conservation of objects containing foam in this condition has been to remove it and replace it (Section 3.1.5). However, in considering conservation possibilities for the *Globe* at one point in the project it seemed most likely that the search for a solution would focus on an investigation of different materials with which to build a rigid structure which could be used to capture the profile of the object and seal the degrading foam beneath it. For the previously described reasons the investigation took a different route. However, such an investigation which identified conservation appropriate materials which could be shaped to capture a profile and then hardened to provide support for top covers or other upholstery layers might offer another solution for crumbling foams. The investigation might begin with the fibreglass caps described by Graves (1990) or the Poliflexsol described by Shashoua and Wills (1994). It would have to consider the impact of such a structure on the preservation of all aspects of an object. It would have to ask whether replacement with another foam actually does more to preserve the entire object than encasing original crumbling material. But it might offer a way to capture evidence of the existence of a no longer functional material while restoring an original outward appearance of a chair. Today, when a tiny fragment of original top cover fabric is found sometimes hundreds of hours and many more pounds are spent to recreate a likeness of that fabric. Although it may sound extremely far fetched, perhaps 100, 200…years from now a tiny fragment of foam will provide the evidence needed to recreate a sample of it for perhaps at some future date the look and feel of polyether polyurethane foam will be unknown to the general public. It is impossible to predict what might be done with tiny fragments of foam but a system of encasing them in place in a twentieth century chair might preserve evidence of them for use in the twenty-second century or beyond.

On the other end of a foam degradation behaviour spectrum is the problem of expanding foams. Several images of chairs presenting this conservation challenge can be found in the previous pages (Figures 6 & 8, Page 9; Figure 73, Page 60; Figure 84, Page 93). Two of these objects exhibit expanded and possibly still expanding foams which have distorted the original profile of the chair and to which top cover fabric is securely adhered. The other two exhibit split seams in top covers which could not be re-stitched unless the expanded foam beneath the top cover was compressed or cut away. This project focused on little investigation which offered time or substance for consideration of this challenge but this reality makes it no less a problem for those caring for foam upholstered furniture. Work to find solutions for these objects needs to be undertaken. Serge Mauduit, Curator of the Collection at the VDM offers the opinion that cutting away expanding foam in order to preserve the majority of the original material while restoring a profile to an object would be preferable to removing and replacing the foam.[142] In developing a method to cut the 2CM pads into samples of a precise size it was found that the use of a hot wire cutter produced a clean cut without melting away excess foam (Section 4.1.1). Perhaps these two small details are the seeds from which an investigation and eventual solutions can be grown.

Both of the previous challenges which result from the changing physical structure of foam have at their roots the process which has been described in Chapter 2. Polyether polyurethane foams degrade by oxidation and hydrolysis as a result of exposure to light, heat, moisture and chemicals. This can also be said of polyester polyurethane foams and foam rubber (Fisher 1957; van Oosten 1999), two other common upholstery foams.

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[142] Personal conversation at the VDM on 4 April 2005

Further work which would investigate ways to slow the degradation of these materials would reduce the need for treatment of crumbling and expanding foams. Such work which might seek to shield these foams from the agents which cause their degradation would not be new. Application of the idea within a storage environment is being used and has been discussed in the description of the slow degradation method (Section 3.1.2). However, if a method could be developed which incorporated the protective measures within the structure of an object rather than around it foam upholstered furniture might be able to be conserved to a way which made it suitable for display but at the same time prolonged the life of the foam it contained. The work described in Section 7.4.4 regarding the inclusion of an antioxidant in an adhesive/consolidant formulation has begun the process of developing such a technique but several references suggest a slightly different avenue for research.

Griffith (1997) comments that Tyvek®, a sheeting of very fine 100% high-density polyethylene fibres, is permeable to acidic degradation products, while offering excellent protection for objects when used as dust covers. At the Canadian Association for Conservation Workshop, 26-27 May 2004, *Unusual Materials, Unconventional Treatments*, Richard Gagnier, conservator at the National Gallery of Canada, Ottawa, commented that storing an art object constructed in part of exposed polyurethane foam in tightly wrapped polyethylene sheeting seemed to be slowing the degradation process.[143] Nuttgens & Tinker (2000) and Winkelmeyer (2002) point to the use of ESCAL™ film to shield objects from oxygen exposure and thus slow degradation. Protective Packaging Ltd markets a range of barrier films promising to shield objects from among other things moisture, ultraviolet radiation and aggressive gases.[144] Perhaps the inclusion of one of these materials, or another as yet unidentified, between the top cover and the foam layer of a piece of upholstered furniture would achieve the desired result.

Whether such a new layer protected the foam from agents of degradation but at the same time created the type of damaging microenvironment previously described (Section 3.1.3) would certainly need to be investigated. The use of oxygen and/or acid

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[143] Information recorded during the presentation Characteristics and Requirements of Contemporary Art in Collections: A Global Approach

[144] http://www.protpack.co.uk/uk/index.html

scavengers in addition to a barrier film could be considered. Whether, in a case like the *Globe*, it would be physically possible to adhere the barrier layer to the foam and then adhere the top cover fabric to the new layer as well as whether the foam would be strong enough to support the extra weight would have to be determined. It has been offered that ESCAL™ contracts with time and is quite rigid in the first place[145] so perhaps it would provide the desired protection but it offers physical limitations which make its use in this circumstance impossible. Tyvek® is permeable to acidic degradation products so it would probably not be a material that would establish a damaging microenvironment but at the same time it seems likely that the material would not shield underlying foam from most agents of degradation. These and no doubt many other questions would need to be answered but identification of a positive solution might result in a way to prolong the life of original materials in foam upholstered furniture while simultaneously making such objects available for display.

Finally, the approach to the conservation of the *Globe* and more than likely any solutions resulting from investigations of the three previous challenges requires or would require significant access to the interface between foam and fabric. However there are plenty of situations where such access is not available. The fabric is well secured at edges in the privately owned chair in Figure 10, Page 11. In the VDM *Ball* SSK-1002 the bond between fabric and foam has begun to fail well inside the edges of the proper left lower cushion. The adhesion techniques tested in this project could not be applied if access to the reverse of the fabric and the obverse of the foam was not available. Therefore, they could not be used in the conservation of the previous two objects while in their current states of degradation without releasing significant portions of original bonds. The development of techniques which would make it possible to re-secure fabric in situations like those above without having to release areas of a bond that are still secure would be another useful direction for further work. Such solutions would make it possible to secure degraded areas when they were still small thus reducing stress on other areas of the fabric, adhesive and foam. Such a process might make it possible to carry out small treatments on an object keeping it available for display rather than removing an object from display because of a visual disturbance which can not actually be repaired until the piece reaches a much greater state of degradation. Such a process

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[145] Personal conversation with David Grattan, Manager, Conservation Process and Materials Research, CCI, 10 June 2004.

would no doubt become an indispensable tool if one were to adopt the maintenance approach suggested in Section 7.3.

7.6 – Still other directions for further research

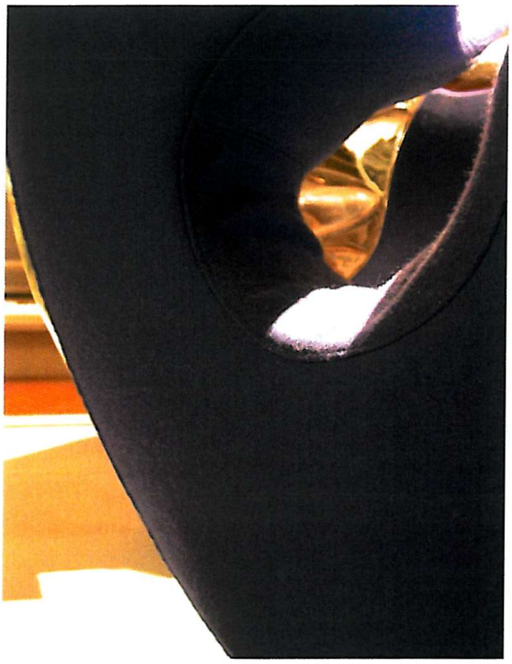
Finally, this research generated ideas for projects which could be carried out to develop tools or a knowledge base that would be of great assistance to future projects like that which has just been described. The first was generated by a growing understanding that in the search for a solution to a conservation problem, rather than a scientific problem, the type of standardized sample set a scientist generally chooses to use is not particularly useful. Such a set is likely to produce repeatable results but the conclusions which can be drawn from the results are 'hardly applicable to real, unrepeatable conservation objects' (Viñas 2005: 129). In order to develop new conservation techniques tests need to be carried out. These tests need to be carried out on surrogate samples. However, if the samples are not similar to the object which will eventually be conserved the results are not likely to be directly applicable. For the *Globe* the problem was over come with the use of the 2CM pads and top cover fabric. For other foam upholstered objects the problem could be more easily overcome with the development of an archive of test material. On a regular basis, twentieth century furniture dealers and upholsterers remove foam and fabric from objects which would be ideal test material. Perhaps relationships with such people could be established and such an archive could be developed.

The second is the realization that for individuals interested in the conservation of twentieth century furniture research into past and current manufacturing techniques would be of great use. An individual well versed in the techniques of traditional upholstery can often look at a piece of furniture and make a very accurate educated guess as to what is beneath the top cover of that piece and what has moved, compressed, broken or in some other way changed to cause the visual changes in the chair. Twentieth century pieces manufactured with new techniques offer new challenges. What is between the layers of fabric in a Charles Eames *Aluminium Group* chair which was designed in 1958? How are the layers of fabric in this chair secured to each other (Figure 132)? How is the fabric in a 1994 Marc Newson *Bucky* chair (MAU-1006/4) at the VDM attached to the understructure (Figure 133)? Better knowledge with respect to how a piece was made in the first place would facilitate the process of deciding how and when it might be conserved. Knowledge with respect to how Ron Arad's 1994 *Soft Little Heavy Chair* (W 6-1994) at the V & A (Figures 134 & 135) was upholstered would be of great assistance in determining whether or not the object is already showing signs of degradation. There is a portion of the top cover fabric which is beginning to buckle. If it was known that the fabric was originally fully adhered to the understructure then bond failure has begun. If the fabric was never adhered in the area presenting the buckle then perhaps the buckle is nothing more than an element of original construction. Some information regarding manufacturing techniques can be gleaned from the publications of authors like Fiell and Fiell (1997 & 2002) and von Vegesack, Dunas and Schwartz-Clauss (1996) but any opportunity to gather first hand knowledge from people, objects or factories should be seized.

▲ Figure 132: *Aluminium Group* chair, designed by Charles Eames, c. 1958 – How are the layers of fabric secured to each other and what is between them? – privately owned (Photo – J. Wickens)

▲ Figure 133: *Bucky* chair, designed by Marc Newson, c. 1994 – How is the top cover fabric secured to the understructure? – VDM – MAU-1006/4 (Photo – J. Wickens)

▲ Figure 134: *Soft Little Heavy Chair*, designed by Ron Arad, c. 1994 – The buckle in the fabric is just below the rear edge of the seat. - V & A – W 6-1994 (Photo – J. Wickens)



▲ Figure 135: Detail of Figure 134, *Soft Little Heavy Chair*, designed by Ron Arad, c. 1994 – Although obscured by the bright light the buckle in the top cover fabric is just visible. - V & A – W 6-1994 (Photo – J. Wickens)

7.7 – Conclusion

The results of the experimental work undertaken during this project considered within the identified needs of the upholstery conservation profession have proven to be fruitful. A solution for the *Globe* which is ready and waiting, almost begging, to actually be put to use has been identified. Conservation recommendations for other *Ball* chairs showing various signs of degradation have been made. Additional recommendations for the larger class of foam upholstered furniture have been able to be offered.

The results and the experimental process behind them have generated a large number of ideas and starting points for further research. If pressed the generation of such ideas could go on and on. Development of analytical techniques which could be used to predict future degradation might be a wonderful, magical tool. It could help with the decision making process which would determine whether to remove and replace degrading foam, encase it or, as in the *Globe,* stabilize it so that it can still perform its original function. However, development of such a tool would do nothing for the chairs which need to be conserved today. Research which developed spot treatment techniques which would make it possible to re-adhere surfaces without having direct access to the surfaces in question would. Development of techniques to build forms which restore profile and encase fragile foam would. Development of an ethic regarding the conservation of expanding foams and techniques to respond to that ethic would. If forced to prioritize these are the directions for further research which would find their way to the top of the list. They would help make more twentieth century foam upholstered furniture displayable, a priority which will be further defined in the concluding pages.

Conclusion – The Possibilities, a Solution for the *Globe*, the Ideas, a Reason

The possibilities which pointed the way to a solution

At the start of this work it was suggested that a solution for the *Globe* might be found in the efforts of those seeking to conserve modern art and particularly modern art works constructed at least in part of foam. In the efforts of these individuals to consolidate degraded foam and adhere things to the consolidated or unconsolidated foam were found roots for a practical solution for the conservation of the *Globe*. In the efforts of the same category of conservators to determine what to do about missing elements, rapidly degrading elements and no longer functional elements of a variety of art works were found ideas about what constituted an ethically appropriate solution for the *Globe*. The work of many to describe why and how the original intent of the artist ought to be preserved in a conservation project contributed to further definition of an ethically appropriate solution for the *Globe*. However, modern art conservators were not the only contributors to the development of a solution.

The work of historians which describes the development of twentieth century furniture shaped ideas about what needs to be conserved. The links these scholars establish between materials and production processes, the influence of such materials and processes on what could not only be imagined but actually produced, and the way such design and production turned chairs into sculpture make it clear that original materials, design and production processes, and original form all need to be conserved in twentieth century foam upholstered seat furniture. An understanding of the development and current practice of upholstery conservation instilled a belief in the intrinsic value of original upholstery materials and the need to conserve them. It also shaped ideas about how such materials might be conserved while simultaneously restoring the profile of the object. At the same time it clarified the influences available time, finances, institutional politics, institutional priorities and practical knowledge have on specific situations which might result in a treatment which could not or did not conserve original materials. The work of conservators of twentieth century furniture shaped ideas regarding the significance of a first intrusion on an object and the importance of minimizing such an intrusion. Conservation theorists shaped ideas regarding what constitutes appropriate intrusion. There is not just one appropriate way to intrude upon and conserve an object. There are many different ways that might be appropriate. The question of for whom the intrusion is being carried out is an important one to answer when trying to define which intrusion is most appropriate. Any intrusion will change an object. It will alter the history of the object. However, if done with the current and/or future users of the object in mind the change is likely to be one many can accept.

The end result is a conservation solution the author believes accepts the value of the original materials in the *Globe* by making a best effort to conserve them in their original location. It also accepts the importance of the design and production process which would have been used to create the *Globe* and therefore uses a conservation method that would do little to obscure these processes. It introduces nothing but new adhesives between the foam and fabric which would have originally been adhered to each other. In order to do so it requires that original stitching is released. However, it leaves evidence of the original stitching in place and reintroduces new stitching through the original stitch holes. It accepts the importance of the original form the *Globe* would have presented at the completion of the production process used to create it. Therefore the solution uses a conservation method that would restore this form. In restoring the original form of the *Globe* it offers a way to conserve the original intent of the designer/artist. It makes the chair appear to be a big, bold, comfortable sitting object once again. Application of the solution would change the *Globe* in irreversible ways but the changes would make the *Globe* more 'usable' today and hopefully do so without limiting its potential use for future generations.

The solution for the *Globe* which pointed the way to other ideas

This solution for the *Globe* which would leave all original materials in place, consolidate the obverse surface of the ageing foam and then re-adhere the original fabric to that strengthened surface has been shown to not only have offered a solution for the *Globe* but pointed the way to ideas regarding possible solutions for other foam upholstered objects and general approaches to their conservation as a class of artefacts. Some of the ideas are quite specific with respect to techniques for interventive conservation. If a polyurethane foam and a wool fabric need to be adhered a polyurethane consolidant and a polyvinyl acetate adhesive film seem to be a good combination of materials with which to carry out the task. If a foam surface needs to be consolidated and the foam is in stable condition it is possible to apply the consolidant with a brush. If an adhesive or a consolidant needs to be used a water-based adhesive is probably safest. Other ideas are a bit further removed from the application of specific interventive techniques. If surrogate materials are being selected for testing their selection should be based on chemical identification as well as physical qualities. An earlier intervention is probably better than a later one. If foam and fabric need to be adhered a two-step application of consolidant and adhesive film is likely to be preferable to a one-step process that uses the same material to consolidate and adhere.

The idea which pointed the way back to a reason

Of all of the ideas which were generated however there is one that seems to speak with the most conviction. It is the idea that if foam upholstered objects are fragile, ephemeral museum objects, if their future as museum artefacts is really quite short-lived then they should be on display now. In order to get some of them on display risks will have to be taken. Treatments which are not guaranteed to work even in the short-term will have to be tried. Treatments which will clearly work in the short-term but may have unexpected long-term affects will have to be tried. However, without trying them the objects may only sit in their current locations slowly or perhaps rather quickly losing the ability to communicate not only what they were originally collected to communicate but anything else which a museum, gallery, historic house or other heritage venue might find useful.

The future of objects made in whole or in part of twentieth century materials which degrade rather rapidly is uncertain. It appears that it will be impossible to preserve these objects so that they will be physically present to influence the lives of inhabitants of this world only a few generations from now. If this is the case perhaps the best thing to do is take some risks and put them into a condition where they can influence the current inhabitants of this world. Perhaps their future is in the minds of the people who have benefited from them today rather than in the minds of those who could benefit from a well preserved object in years to come. By planting them firmly in the minds of today they will be preserved for posterity in the memories they create and the ideas they engender.

Perhaps objects like the Charles Eames prototype in Figure 83, Page 93 will be found to be so degraded that their function as anything beyond a study object has disappeared. Perhaps the best that can be done with these objects is they can be stored in a way that slows their degradation but at the same time leaves them available for researchers. Then as with *59-18* (Section 3.1.1) when the object has degraded so much that it is no longer even useful for researchers it will be de-accessioned and disposed of in some way or another. For other objects perhaps the conservation process will find that in fact there is still displayable life in them. Like *Still Life of Watermelons* they may have been considered complete losses but through conservation efforts not found to be so. Such appears to be the case for the *Globe.* It has been shown to be the case for an Ernest Race

Heron chair and *Locus Solus* (Section 3.1.4). There is no reason to think it will not be the case for other foam upholstered furniture. And through investigations regarding how to go about conserving one foam upholstered object conservation solutions for others might be found. The process will allow the pieces to be returned to display in temporary exhibitions or 'permanent' galleries giving them the opportunity to impress the minds of today. In so doing they will create in those minds what Ward (Page 1) has termed 'memories of our human progress' and this document has re-termed memories of our human journey.

In the process 'mistakes' will be made. Treatments designed to prolong the life of an object will accelerate its degradation rather than slow it. It will be discovered that materials which were left *in situ* should have been removed. Materials which were removed will become the evidence someone would give anything to still have in place. However, if the process of determining a solution has been undertaken with great care and the solution gives every indication that it is the best available today then what happens in the future, choices that hindsight shows are 'better', can not be waited upon. In the waiting pieces may decay beyond the point of help and only in the trying is the knowledge that produces the gift of hindsight developed. If there is one thing this project has left for the author it is a better understanding that conservation needs to be used to make objects available to people. Waiting around for the perfect solution does nothing for the people who could be using objects today. In any project Viñas's (2005) future users need to be catered to but not at the expense of the current users who might be the only people ever lucky enough to use the object in the first place.

Appendix 1 – Current Needs Survey

An informal survey of curators and conservators responsible for the care of upholstered furniture was carried out in the early stages of this project. As referred to in the Preface, one of the goals of this survey was to determine what some of the current conservation challenges in the field of upholstery conservation were. By written request (Page 264), individuals at approximately 60 institutions primarily in the United Kingdom and the United States were invited to participate. 33 individuals (Table 33, Page 265) responded by letter, email or phone providing information relevant to the defined goal. When a phone conversation or an email communication proved the means by which information was gathered the following list of eight questions was used to guide the process.

1. Tell me a little bit about your institution and your approach to the care of the upholstered items there.
2. Do you have upholstered seat furniture in your collection which retains upholstery understructures made of twentieth century synthetic materials?
3. Do you have an object in your collection that retains an original top cover or a top cover which has been identified as historically significant which you feel you can not display for reasons of aesthetics or stability?
4. Thinking five to ten years into the future, what do you imagine will be your primary challenges with respect to being able to care for and display the upholstered seat furniture in your collection?
5. How do you set priorities with respect to the order in which pieces are conserved?
6. If someone had two years to carry out research and/or experimentation, what one or two things could he/she look into or produce that would help you achieve the goals you have set with respect to the care and display of your upholstered furniture?
7. Who carries out most of your upholstery conservation?
8. Are there other curators you would suggest I speak to?

A sample of a written request for an interview:

Joelle D. J. Wickens
The Flat, 1 Park Road
Winchester, Hampshire
SO22 6AA
Tel 01962 861409
E-mail Joelle.Wickens@soton.ac.uk

11 February 2004

Peter Trowles MLitt FRSA
Taffner Curator, Mackintosh Collection
Glasgow School of Art
167 Renfrew Street
Glasgow
G3 6RQ

Dear Mr. Trowles,

My name is Joelle Wickens and I am currently carrying out PhD research in the field of upholstery conservation, under the supervision of Kathryn Gill, at the Textile Conservation Centre, University of Southampton. As part of this research I am in the process of identifying specific upholstery conservation challenges (not directly related to lack of funding) which are preventing some upholstered objects from being available for display.

It is my understanding that you are responsible for upholstered objects in the Mackintosh Collection at the Glasgow School of Art. Due to your role I am very keen to find out what your current primary concerns are with respect to the care and display of the upholstered objects in your collection. However, if upholstered items do not fall into your area of care would you kindly pass this letter on to the person in your institution who does have this responsibility?

Initially, I would like to have a brief phone conversation with you during which you could share with me basic information about the pieces in your collection currently creating display problems. I would be particularly interested in hearing about problem pieces which retain:

- original upholstery understructures made of 20th century synthetic materials;
- historically significant top covers and can't be displayed for reasons of aesthetics or stability.

However, as my primary goal is to discover what your current conservation needs are please use these ideas as only a starting point not a confining set of parameters.

Within the next few months, I intend to design an experimentation plan to investigate and develop conservation techniques which meet the concerns defined by you and your colleagues. Ultimately, I will carry out this plan and share the results of my research with the wider historic preservation community, insuring that the maximum number of people benefit from the time and effort expended by all those involved in the process.

Please let me know by email, post or telephone if you would be prepared to speak with me. If so, please include your telephone number in the communication and I will contact you as soon as possible.

Thank you in advance for taking time to consider the points above. I look forward to hearing from you.

Sincerely,

Joelle Wickens

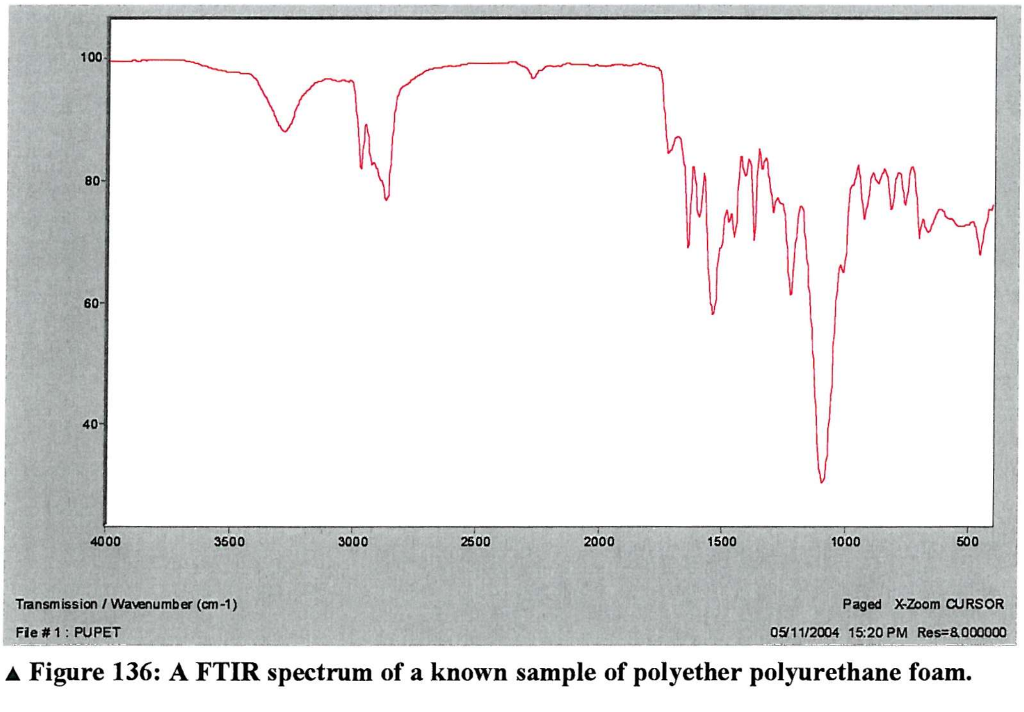
Table 33: The 33 curators and conservators who responded to the request on Page 264.

Name	Position	Institution
Michelle Barger	Conservator of Objects	San Francisco Museum of Modern Art San Francisco, CA, USA
Tim Bechthold	Conservator	Die Neue Sammlung München, Germany
Stella Beddoe	Keeper of Decorative Arts	The Royal Pavilion, Libraries & Museums Brighton, UK
Bob Bird	Senior Curator, 3D Collections	London Transport Museum London, UK
Steven Blake	Museum and Collections Manager	Cheltenham Art Gallery & Museum Cheltenham, UK
Kevin Booth	Senior Curator (Acting)	Dover Castle, English Heritage Dover, UK
Tim Burgard	Curator of American Art	Fine Arts Museum of San Francisco San Francisco, CA, USA
Tara Chicirda	Associate Curator of Furniture	The Colonial Williamsburg Foundation Williamsburg, VA, USA
Frances Collard	Curator, Department of Furniture, Textiles & Fashion	V & A London, UK
Ulysses Grant Dietz	Curator	The Newark Museum Newark, NJ, USA
Roger Griffith	Associate Sculpture Conservator	MoMA New York, NY, USA
Gareth Hughes	Curator	Audley End House & Gardens, English Heritage Saffron Walden, UK
Jackie Hunt	Collections and Interpretations Officer	Wycombe Museum High Wycombe, UK
Michael Hunter	Curator	Osborne House, English Heritage Isle of Wight, UK
Matthew Jarron	Curator of Museum Services	University of Dundee Museum Service Dundee, UK
Tom Johnson	Curator of Collections	Old York Historical Society York, ME, USA
Claire Jones	Keeper of Furniture	The Bowes Museum Barnard Castle, UK
Kathrin Kessler	Conservator	Vitra Design Museum Weil am Rhein, Germany
Joshua Lane	Assistant Curator of Furniture	Historic Deerfield Deerfield, MA, USA

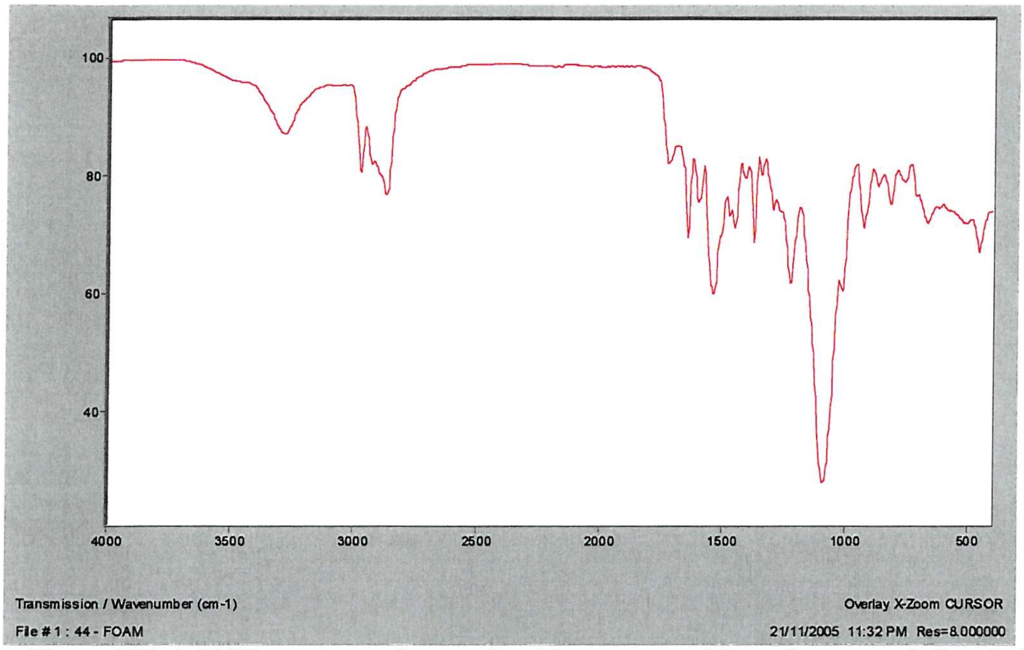
Name	Position	Institution
Peter Lundskow	Conservator	Indiana State Museum and Historic Sites Indianapolis, IN, USA
Serge Manduit	Curator of the Collection	Vitra Design Museum Weil am Rhein, Germany
Holly McGowan-Jackson	Senior Conservator of Frames and Furniture	National Gallery of Victoria Melbourne, Australia
Angela Meincke	Furniture Conservator	Museum of Fine Arts Boston, MA, USA
John Miller	Centre Manager	Frederick Parker Collection of Chairs London Metropolitan University London, UK
Lee Miller	Curator of European Art	Fine Arts Museum of San Francisco San Francisco, CA, USA
Paul Miller	Curator	The Preservation Society of Newport County Newport, RI, USA
Darren Poupore	Curator of Collections	Biltmore Company Asheville, NC, USA
Clare Stoughton-Harris	Textile Conservator	Museum of Welsh Life Cardiff, UK
Reena Suleman	Curator of Collections and Research	Linley Sambourne House London, UK
David Thickett	Conservation Scientist, Collections Care Team	English Heritage London, UK
Evelyn Trebilcock	Curator	Olana State Historic Site Hudson, NY, USA
Peter Trowles	Taffner Curator, Mackintosh Collection	Glasgow School of Art Glasgow, UK
Susan Walker	Curator	Staatsburgh State Historic Site Staatsburgh, NY, USA

Appendix 2 – FTIR Spectra

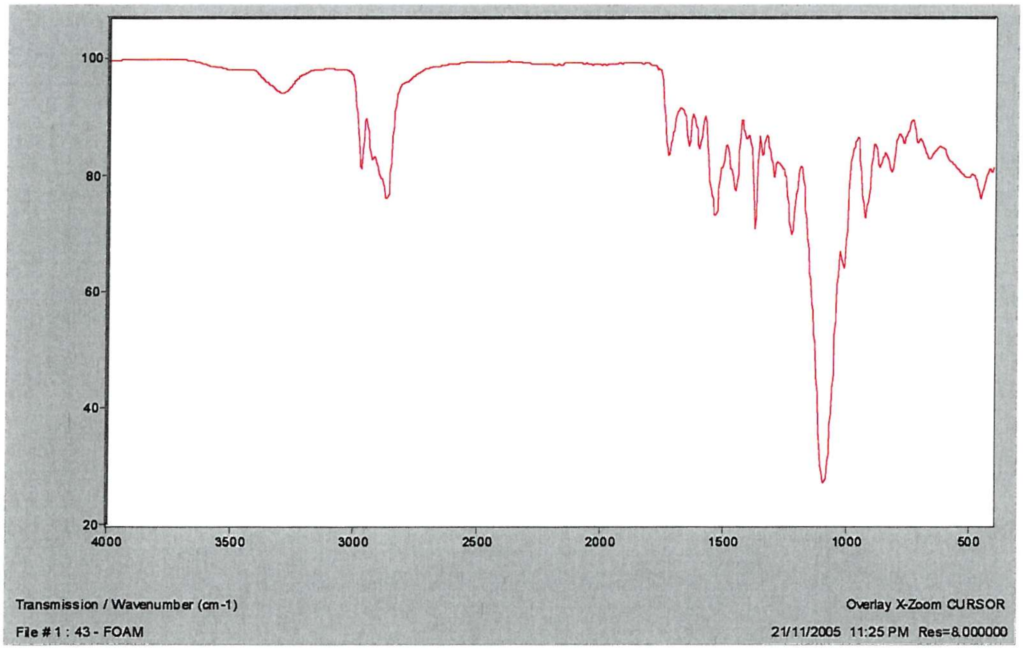
Figures 136 - 142 below present the FTIR spectra which were used to identify foam used in the *Globe*, the Vitra Design Museum's *Ball* (SSK-1002) and the current manufacture of *Ball* chairs as polyether polyurethane. Figure 143 shows the spectra which help to identify the adhesive used to secure top cover to foam in the *Globe* as a polychloroprene-based. All spectra were acquired with a Perkin Elmer Spectrum One FT-IR Spectrometer equipped with a universal attenuated total reflectance (ATR) sampling accessory. In each case a sample was placed on the diamond crystal of the ATR accessory and clamped in place. Spectra were recorded from 4000 to 400 cm^{-1} with a resolution of 8 cm^{-1}, and averaged over 16 or 64 scans. The spectra were processed with Thermo Galactic Grams/AI (7.02) software. Figure 143 presents spectra displayed in Absorbance. All other spectra are displayed in Transmittance.



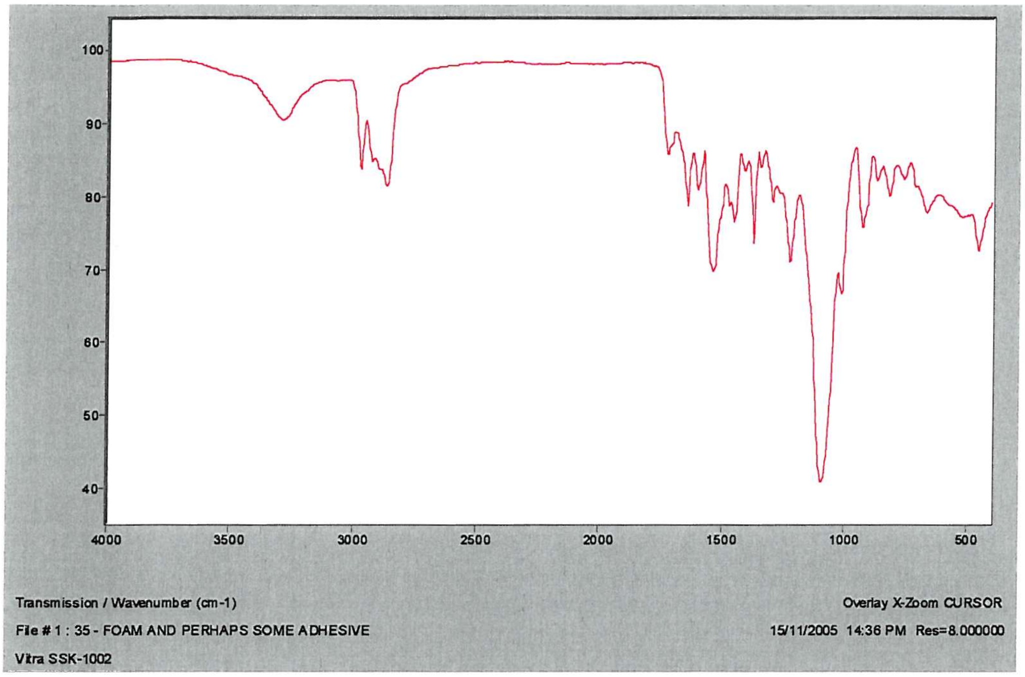
▲ **Figure 136: A FTIR spectrum of a known sample of polyether polyurethane foam.**



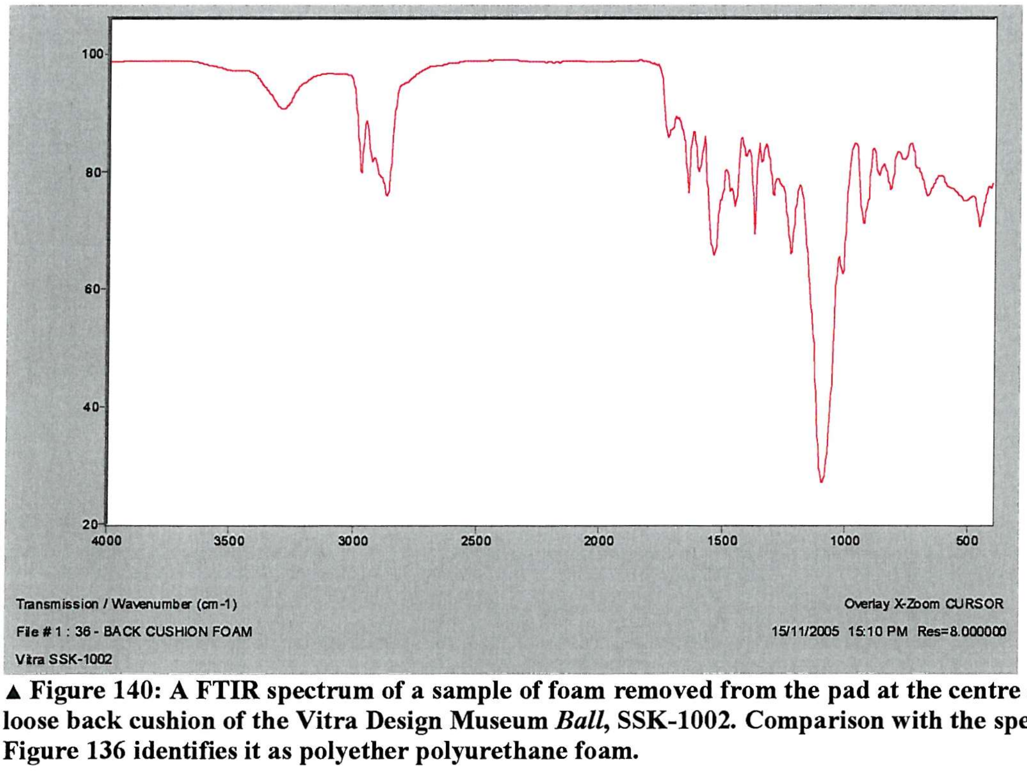
▲ **Figure 137: A FTIR spectrum of a sample of foam removed from the proper left pad of the *Globe.* Comparison with the spectrum in Figure 136 identifies it as polyether polyurethane foam.**



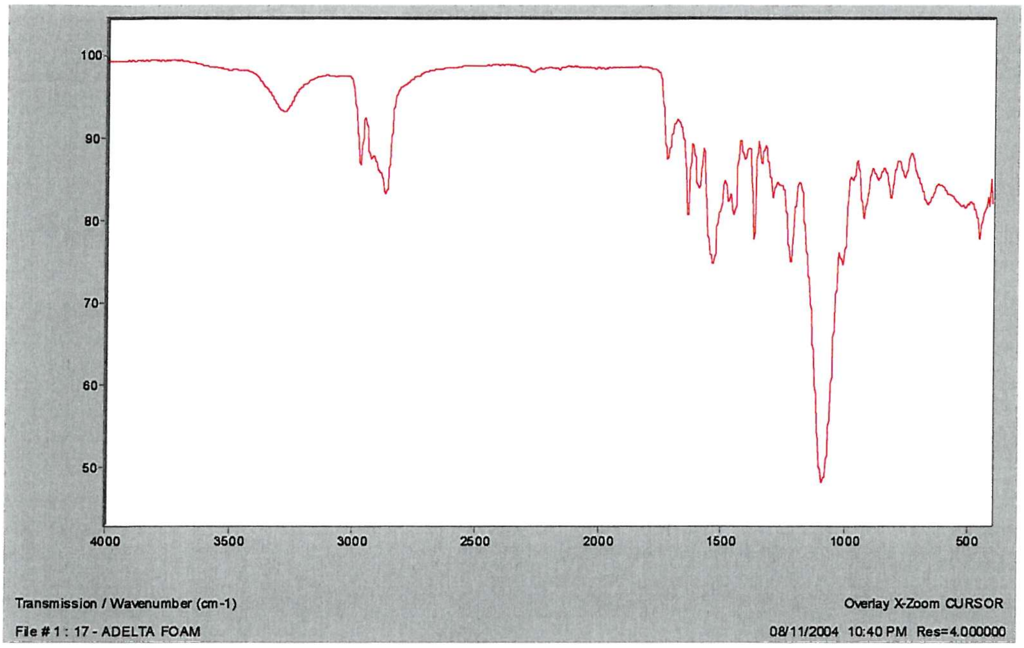
▲ **Figure 138: A FTIR spectrum of a sample of foam removed from the pad at the centre of the loose back cushion of the *Globe.* Comparison with the spectrum in Figure 136 identifies it as polyether polyurethane foam.**



▲ **Figure 139: A FTIR spectrum of a sample of foam removed from the proper left bottom pad of the Vitra Design Museum *Ball*, SSK-1002. Comparison with the spectrum in Figure 136 identifies it as polyether polyurethane foam.**

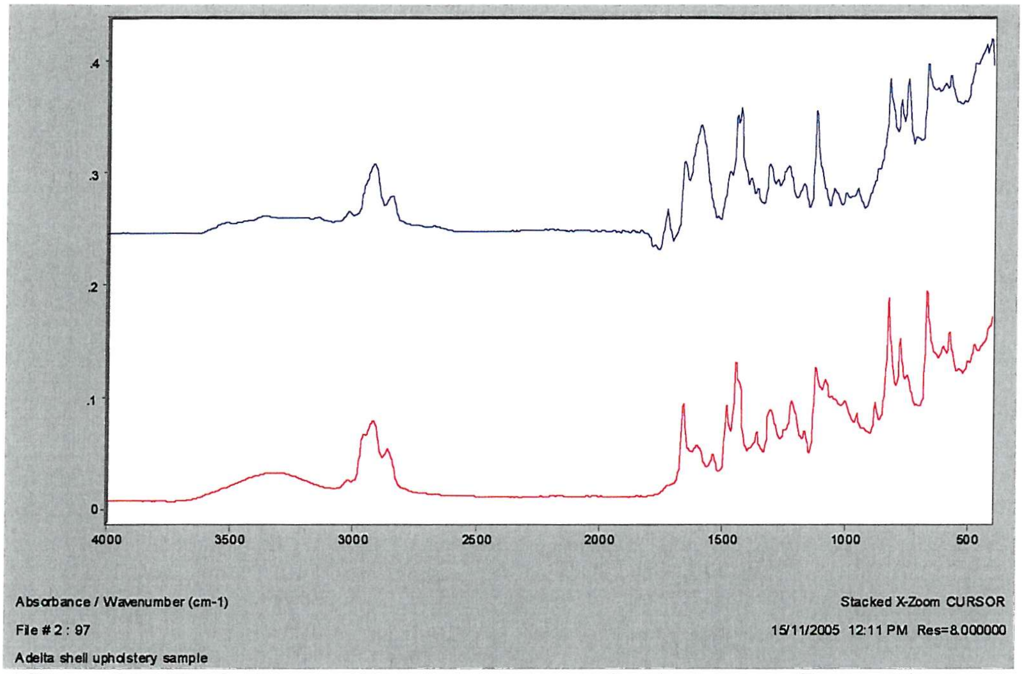


▲ **Figure 140: A FTIR spectrum of a sample of foam removed from the pad at the centre of the loose back cushion of the Vitra Design Museum *Ball*, SSK-1002. Comparison with the spectrum in Figure 136 identifies it as polyether polyurethane foam.**



▲ **Figure 141: A FTIR spectrum of a sample of the foam currently used to upholster the shell of *Ball* chairs. Comparison with the spectrum in Figure 136 identifies it as polyether polyurethane foam.**

▲ **Figure 142: A FTIR spectrum of a sample of the foam currently used to pad the loose seat cushion of *Ball* chairs. Comparison with the spectrum in Figure 136 identifies it as polyether polyurethane foam.**



▲ Figure 143: The bottom spectrum is of a known polychloroprene adhesive. The top is of the adhesive used to secure fabric to foam in the shell of the *Globe.* There are matching peaks at 577, 670, 780, 830, 1123, 1447 and 1484. This indicates that the *Globe* adhesive is polychloroprene based but not an exact match to the known polychloroprene, Vertex K-400.

Appendix 3 – Objects Referenced in Text

Listed alphabetically below are the specific objects which have been referred to in the main text of this document. Each entry includes if possible: ***object name***, designer, date of design (date of object if different from design), institution which holds the object, the catalogue number for the object (bibliographic reference if available)

59-18, Henk Peeters, c. 1959, Netherlands Institute for Cultural Heritage, no catalogue number provided (Rodrigo & Beerkens 1999)

Aluminium Group, Charles Eames, c. 1958 (exact object date unknown), privately owned, no catalogue number provided

American Easy Chair, unknown designer, c. 1780, unknown owner, no catalogue number provided (Battram 1994)

Animal Preserve No. 2, Iain Baxter, c. 1999, National Gallery of Canada, Ottawa, 40101.1-503

Armadillo, Designers Associated Milan, c. 1969 (object date not provided), V & A, London, no catalogue number provided (Griffith 1997)

Ball, Eero Aarnio, c. 1963 (exact object date unknown), Montreal Museum of Fine Arts, D87.245.1

Ball, Eero Aarnio, c. 1963 (exact object date unknown), Sotheby's, London, Lot 146, Sale L05814

Ball, Eero Aarnio, c. 1963 (exact object dates unknown), Vitra Design Museum, Weil am Rhein, MSK-1001-1, MSK-1001-2 and SSK-1002

Blow, Gionatan de Pas, Donato D'Urbino, Paolo Lomazzi and Carla Scolari, c. 1967 (object date not provided), V & A, London, Circ. 100-1970 (Griffith 1996)

Bucky, Marc Newson, c. 1994 (exact object date unknown), Vitra Design Museum, Weil am Rhein, MAU-1006/4

Coconut, George Nelson, c. 1955 (exact object date unknown), Vitra Design Museum, Weil am Rhein, MUS-1066/2

Cone (prototype), Vernor Panton, c. 1959, Vitra Design Museum, Weil am Rhein, MPA-1012

Denon Chairs, Baron Dominique Vivant Denon (1747-1825), early nineteenth century, V & A, London, W.6-1996, and National Museums and Galleries on Merseyside, WAG-1996.64 (Balfour et al 2001)

Dolphin Chairs, unknown designer, c. 1670, Ham House, Richmond-upon-Thames, no catalogue number provided (Gentle 1984 & 1990)

Egg (chair and ottoman), Arne Jacobsen, c. 1957 (1963), Museum of Fine Arts, Boston, no catalogue number provided

Funburn, John Chamberlain, c. 1967, Museum für Moderne Kunst, Frankfurt/Main, no catalogue number provided (Winkelmeyer 2002)

Globe, Eero Aarnio, c. 1963 (1968), V & A, London, Circ. 12-1969

Heron, Ernest Race, c. 1955 (exact object date unknown), Geffrye Museum, London, 1/1993/1&2 (Gill 2001)

Kaufmann Office, Frank Lloyd Wright, c. 1935 – 1937, V & A, London, no catalogue number provided (Wilk 1993; Wilson 1999)

Locus Solus, Gae Aulenti, c. 1964 (exact object date unknown), Union Centrale des Arts Décoratifs, Paris, no catalogue number provided (Vandenbrouck 2004)

Mare, Piero Gilardi, c. 1966, unknown owner, no catalogue number provided (Rava et al 2004)

Ministry of Defence Armchair, unknown designer, n.d., English Heritage, no catalogue number provided

My Bed, Tracey Emin, c. 1998, White Cube, London, no catalogue number provided (Hale 2004)

Pastil, Eero Aarnio, c. 1968, V & A, London, Circ. 13-1969

Pratone, Gruppo Strum, c. 1966-1970 (object date not provided), Museum Kunst Palast, Düsseldorf, no catalogue number provided (Butzer 2002)

Pratt Chair No. 2, Gaetano Pesce, c. 1984, Vitra Design Museum, Weil am Rhein, no catalogue number provided (Albus et al 2007)

Prière de Toucher, Marcel Duchamp, c. 1947, Chapin Library of Rare Books, Williams College, Williamstown, Massachusetts, no catalogue number provided (Grattan & Williams 1999)

Routemaster Bus, unknown designer, c. 1956, London Transport Museum, no catalogue number provided

Sacco, Piero Gatti, Casare Paolini and Franco Teodoro, c. 1968 (object date not provided), V & A, London, Circ. 73-1970 (Griffith 1996 & 1997)

Sit Down, Gaetano Pesce, c. 1975-1976 (exact object date unknown), Vitra Design Museum, Weil am Rhein, no catalogue number provided

Soft Little Heavy Chair, Ron Arad, c. 1994, V & A, London, W 6-1994

Still Life of Watermelons, Piero Gilardi, c. 1967, Museum Boijmans Van Beuingen, Rotterdam, no catalogue number provided (de Jonge 1999; Lorne 1999; van Oosten & Keune 1999)

Swan Collection, Jean-Baptiste-Claude Sené and Claude-François Capin, late eighteenth century, Museum of Fine Arts, Boston, no catalogue number provided (Bonnet & Jamet 2003; Moyer et al 2003)

Trans-Am Apocalypse No. 2, John Scott, c. 1993, National Gallery of Canada, Ottawa, 37493

Tulip, Eero Saarinen, c. 1955 – 1956 (object date not provided), MoMA, New York, no catalogue number provided

Trolley Bus, unknown designer, c. 1931, London Transport Museum, no catalogue number provided

Unnamed chair, Jean Baptist Tilliard I, mid eighteenth century, Detroit Institute of Arts, Acc. no. 60.89 (Lahikainen 2001)

Unnamed chair, Nicolas Heurtaut, mid eighteenth century, Cleveland Museum of Arts, Acc. no. 1989.160 (Lahikainen 2001)

Unnamed chair, possibly Robin Day, twentieth century, privately owned, no catalogue number provided

Unnamed chairs, possibly William Kent, c. 1730, Chiswick House, Chiswick, no catalogue number provided (Gill & Eastop 1997)

Unnamed prototype, Charles Eames, n.d., Vitra Design Museum, Weil am Rhein, no catalogue number provided

Glossary of Terms

Beva® 371 Film	An adhesive in film form with is composed of a mixture of ethylene – vinyl copolymers and tackifying hydrocarbon resins in petroleum solvents of about 55% aromatic content. The solids content of the film is approximately 40%.
Boucle	A yarn which is usually three-ply with one of the threads looser than the others. This loose thread forms loops in the yarn and when the yarn is then woven into a fabric structure it gives the final product a rough, nubby appearance.
Elongation	The ability of a textile to extend when subjected to mechanical forces.
ESCAL™ film	A transparent barrier film made with polypropylene and a vacuum deposited ceramic. The film has a very low transmission rate for most gases.
Ethafoam®	Polyethylene foam made by Dow®.
Hexlite®	Aluminium centred honeycomb board with a woven glass fibre reinforced epoxy skin (previously known as Aerolam®).
Impranil® DLV	An anionic aliphatic polyester-polyether polyurethane aqueous dispersion with a solids content of approximately 40%. It is made by Bayer MaterialScience and marketed as a product for the coating of textiles.
Isinglass	A protein based adhesive which is almost pure gelatine and produced from the swim-bladder of a variety of fish.
Klismos	An ancient Greek chair form characterized by a broad top rail and curved back stiles and legs which was revived in the late 18th and early 19th centuries.
Lascaux 360 HV	An acrylic adhesive supplied as an aqueous dispersion of a thermoplastic copolymer butyl-methacrylate thickened with acrylic butylester. It is manufactured by Lascaux Restauro.
Latex	The aqueous milky juice which flows in microscopic tubes in the bark and roots and sometimes in the stems and leaves of plants – the best source is the rubber tree, *Hevea brasiliensis* – the latex from this tree contains approximately 30 to 35 per cent rubber particles (Fisher 1957: 58 & 67).
Melinex™	A clear, polyester film made by DuPont.

Parylene C	An inert, hydrophobic, optically clear biocompatible polymer coating material.
Parylene N	A different formulation of Parylene C.
Plastic	Any of various organic compounds produced by polymerization, capable of being moulded, extruded, cast into various shapes and films, or drawn into filaments used as textile fibres .
Plastazote®	A closed cell, cross-linked polyethylene foam.
Plextol® B-500	An acrylic resin supplied as an aqueous dispersion of an ethyl acrylate and methyl methacrylate based copolymer with a 50% solids content. It is manufactured by Lascaux Restauro.
Poliflexsol	A light-curable, fiberglass-reinforced polyester resin which is supplied in sheet form.
Primal B-60	As reported by Rava et al (2004), an acrylic latex with a 46-48% solids content manufactured by Rohm and Haas. However a Decmeber 2007 search of their website (http://www.rohmhaas.com/wcm/index.page?) returns no such product.
Tyvek®	Sheeting formed by using continuous and very fine fibers of 100 percent high-density polyethylene in a randomly distributed and nondirectional orientation. It is made by DuPont.

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