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# Packing: A Case Study

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## Introduction

For a period before 1982 paintings loaned by the National Gallery were packed in cases provided by the agents responsible for their transport. For long journeys overseas a double-case system was specified. The paintings, cushioned with pads made from wood shavings in brown paper, were placed in an inner case of unvarnished plywood which was screwed shut. The inner case was placed into a crate constructed from plywood reinforced with softwood battens and lined with expanded polystyrene. The lid of the crate was attached with screws or captive bolts. For paintings travelling within the UK the inner case was dispensed with and the painting was packed directly into the outer crate.

Packing methods and materials have improved considerably in recent years and specialist packing companies have been established to cope with the growing demands of the electronics and defence industries. The type of protection required by delicate electrical equipment is similar to that necessary for the protection of a painting during transport. The packing companies are able to design lightweight and adaptable cases which provide as good, if not better, protection as the double-cases.

## Packing case requirements

Writers agree that the function of a packing case is to protect its contents against impact, shock and vibration, to provide a reasonably watertight seal and to buffer the internal environment of the case against external changes of temperature and relative humidity (RH) [1–3].

As with an exhibition case, a packing case provides a local environment around the painting. The rate of air exchange between the case and its surroundings depends on how efficiently the case is constructed and sealed. This rate should be as low as possible. An efficient seal not only prevents water entering the case during a rainstorm but is also required for limiting the effect of external changes in RH. Preferably this seal should also be able to withstand the changes of pressure that occur during air transport [2]. The case should not be constructed of, and also not contain, any material that gives off vapours that might harm paintings. For example, solvent adhesives should be allowed sufficient time to dry before a painting is enclosed in the case. The concentration of solvent might build up sufficiently within the case to soften varnish or even paint. Padfield has given a list of materials that are considered safe for the construction of cases [4].

Although moderate changes in temperature are not, in themselves, damaging for paintings, their effect on RH can be. The RH within a well-sealed case that has been closed at a temperature of 20°C and an RH of 55% will rise above its dewpoint at 10°C and moisture will condense if the case contains no moisture-absorbent material to buffer the changes in RH. These changes in RH can be restricted in two ways. The thermal insulation of the case can be good enough to maintain the temperature inside the case during the time that a case is in transit. Or humidity buffering materials such as silica gel can be carried inside the case to maintain the relative humidity within reasonable limits. These reasonable limits should be $55\% \pm 10\%$ and any change should not be sudden. The painting and the moisture-absorbent materials associated with it, such as the frame and backboard, will also buffer the RH, but less efficiently than silica gel.

The most suitable way of protecting a painting against shock is to pack it with a cushioning material that compresses on impact and thus absorbs the shock, allowing the painting to come to rest in a controlled manner when a case is dropped or shunted. To perform efficiently these materials should be correctly loaded (the weight per unit area is calculated from cushion performance data) and should be sufficiently thick so that they are not over-compressed when the case is dropped. Polyethylene and polyurethane (polyester or polyether) foams are suitable cushioning materials for the packing of paintings. These foams should be made by blowing with inert gases rather than by catalytic reaction; the latter method can leave volatile residues whose concentrations may build up within a closed case. Fortunately both of these foamed plastics are also good thermal insulators and thus serve a double purpose when used to line a case. The polyethylene foams are denser and compress less than the polyurethane foams and can therefore be used in thinner cushions.

The isolation of a painting from damaging vibration within a case is complicated and may even require spring-loading an inner container within an outer. For the present we feel that such an arrangement may be too elaborate, and a precaution that we can take is to test that the case and packing materials do not resonate (amplify) the vibrational frequencies that occur in the common forms of transport.

The case should be able to withstand impacts from fork-lift truck tines and other hazards. It should also be able to withstand drops from reasonable heights without breaking. It should be designed to ensure easy handling. For example, appropriately positioned blocks on the bottom of the case will allow fork-lift truck tines to be slipped under, and handles will help staff to move the case more safely. It is preferable for the closing devices to be designed for use without tools. Screw-holes that are repeatedly used lose their threads in wooden cases; captive bolts with metal plates are better. The outside of cases should be marked to indicate that the contents are fragile and which way up the case should be positioned.

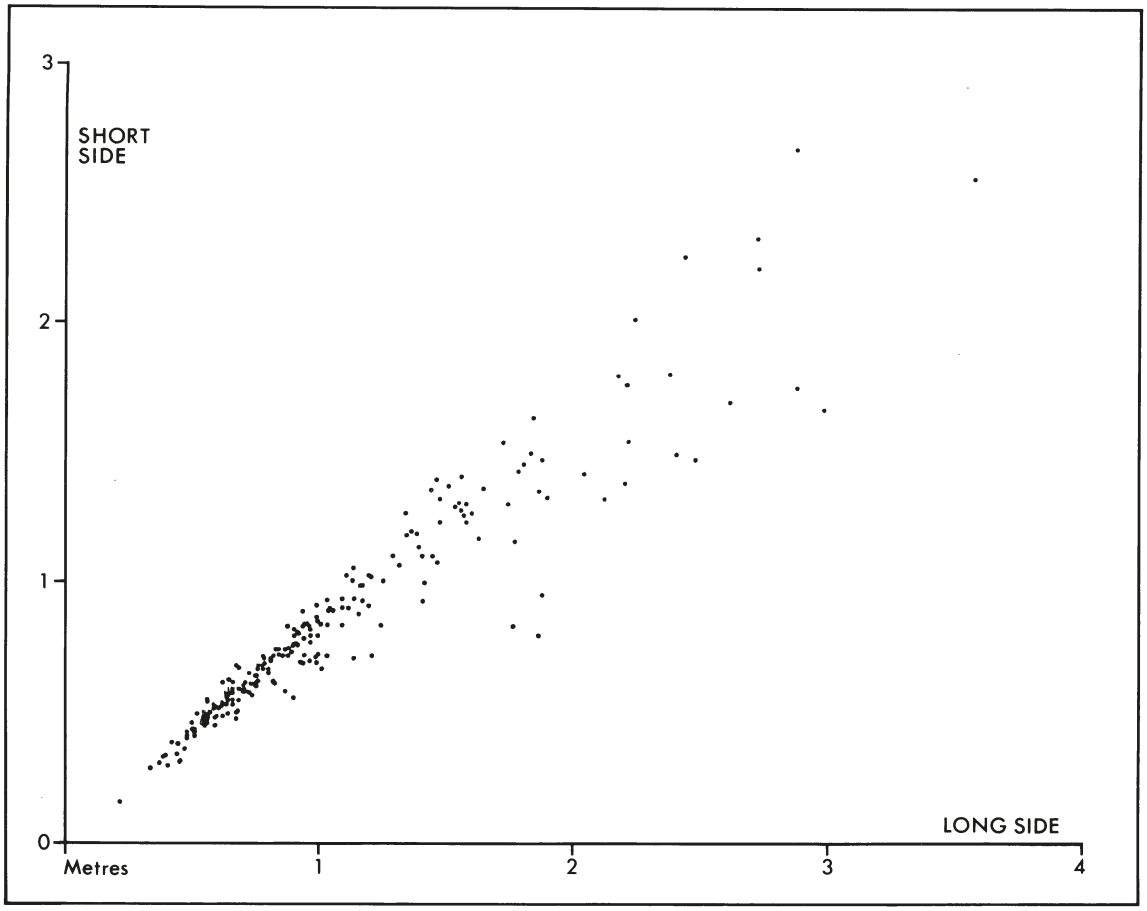


**Figure 1** Scatter plot of frame sizes for 250 National Gallery pictures.

Paintings should be transported in the vertical plane to minimize the effects of vibration and where possible (i.e. for landscape format) in the orientation in which they hang. Since cases are more stable when standing on a long edge, portrait format paintings have to be transported on their sides.

## Standard sizes

Before 1982 every painting loaned by the National Gallery was transported in a tailor-made case. When the painting returned to the Gallery the case was usually discarded. It is more satisfactory to have a range of cases of standard sizes that are designed to be re-usable by adjusting the cushioning within the case to fit a particular painting.

To determine suitable standard sizes a sample of frame sizes of 250 National Gallery paintings that have been loaned was surveyed. For the purposes of this calculation the long and short sides of the frames are considered rather than the height and width since the paintings always travel with a long side at the bottom of the case for the reasons described in the last section.

A scatter plot of long side against short side is shown in Fig.1. This plot shows that the ratio of long side to short is quite similar for most paintings. If this ratio is preserved in the cases the majority of paintings will fit into the appropriately-sized case with similar amounts of space to be filled on each side.

The frame sizes for which 25%, 50% and 75% are smaller were determined. These sizes are:

| | |
|---|---|
| 25% | 680 × 555 mm |
| 50% | 940 × 740 mm |
| 75% | 1460 × 1110 mm |

The difference in size between the last two is rather large. A frame which is 950 × 750 mm would be too large for the second size but would require 510 × 360 mm of space within the third size to be filled. This would make the case unnecessarily large for the painting. A size half-way between the two larger sizes would accommodate 70% of the frame sizes within the survey. The depth of frame is seldom greater than 125 mm and all cases can be made to fit frames of this maximum depth.

The frame sizes for which four suggested standard sizes of cases should be made are given in Table 1. Pictures that are larger than the standard sizes have tailor-made cases. It is also possible to re-use these if large paintings of similar size are requested for loan.

## National Gallery cases

The first contact between the Gallery and Dristyle Products Ltd [5] was in 1971 when Garry Thomson requested a feasibility study on a packing case for paintings. We renewed contact in 1981 and asked them to design cases for the transport of paintings based on the requirements outlined in the second section of this article.

They designed two types of case: Style 1 for the three smaller standard sizes and Style 2 for the larger standard size and the tailor-made large cases.


**Figure 2**
(Above)
Style 1 case containing painting, with Style 1 case on the right and Style 2 case behind.

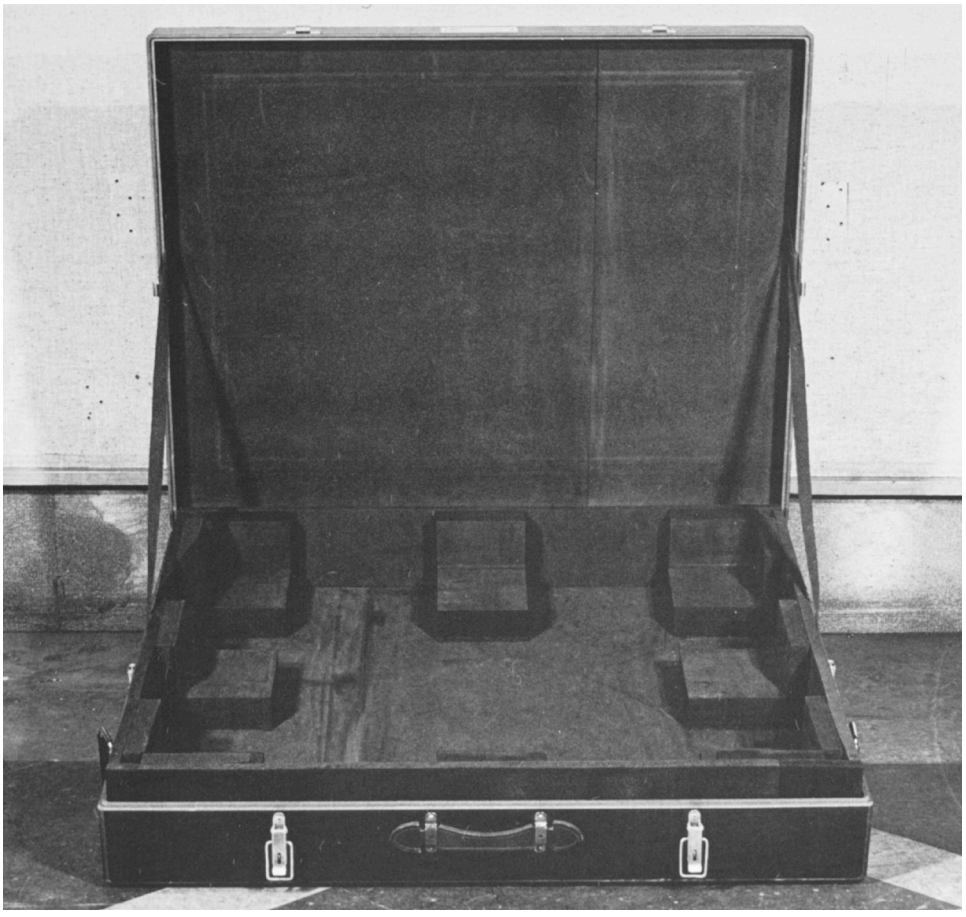

**Figure 3**
(Right)
Inside of Style 1 case.

*Style 1*

Panels of 9mm phenolic-coated or double-faced-aluminium plywood are joined with a polyurethane elastomer moulding to form a strong, flexible, weather-proof construction. The same elastomer is moulded to provide an interlocking seal between the base and lid. The lid is hinged to the base with an aluminium piano hinge and on each side there are webbing restrainers connecting the lid to the base to prevent the lid from opening flat. The case is closed with quick-release fasteners which either incorporate a lock or can be secured with padlocks. These fasteners have a positive closing action and are positioned so that a good seal is made between the lid and base. Spring-loaded handles are fitted to the case and the two smaller standard sizes can be lifted by one person using a heavy-duty leather suitcase handle.

The case is lined with 25mm of the closed-cell polyethylene foam 'Plastazote' [6]. The painting sits on cushions of the same foam. These are cut to size for each painting. Their minimum size is 25mm underneath the painting and 25mm on each side. The frame is directly in contact with the lining of the lid of the case. The number and positioning of these cushions depends on the size of the frame and its ornamentation. The foam is easily cut with a knife and the cushions are held in position using double-sided adhesive tape.

The thickness of the foam lining, the foam cushions and the plywood makes the width and length of the case 120mm and the depth 95mm greater than the frame sizes. The weights and external dimensions of the cases are given in Table 1. The cases are finished with elastomer feet on the base and softwood skids with elastomer pads on the standing (long) edge either side of the piano hinge to protect it when the case is standing upright. Internationally-recognized symbols for 'right-way-up', 'delicate contents' and 'protect from rain' are stuck on the outside.

*Style 2*

To increase rigidity softwood battens are attached to the exterior of the larger cases. Blocks are placed on the standing edge so that it can be lifted by a fork-lift truck. The lid can be lifted off the base and a seal is made using a self-adhesive PVC-foam tape attached to the lid around the join. The same fastening system and spring-loaded handles are used as for the Style 1 cases. The cases are lined with 50mm of the 'Plastazote' foam and the painting sits on an appropriate number of cushions of the foam of minimum thickness 25mm.

Fig.2 shows the two styles of case. Fig.3 shows the inside of a Style 1 case.

## Packing procedure

Cases are allowed to equilibrate at Gallery conditions for at least a fortnight before the painting departs. Although the materials from which the cases are made have low moisture absorption properties, some water may adsorb on the surface of the foam.

Foam cushions are cut, positioned and taped to ensure that the painting is firmly supported within the case. Polyester tape is stretched around the frames of large unglazed paintings to prevent the Polythene in which the painting is wrapped from touching the surface. Silica gel bags conditioned at 55% RH are taped to the backing board of the painting. 1kg of silica gel per cubic metre of air within the Polythene is sufficient for journeys lasting less than a week. The painting is wrapped in a sealed Polythene envelope to provide a waterproof barrier and conditioned environment around the painting.

Paintings are generally placed face-up in the cases so that the surface of the painting can be seen as soon as the case is opened. Occasionally if the picture has an elaborately carved frame it is more convenient to pack it face-down with the foam cushions distributed to avoid contact with the most delicate parts of the frame. If the paintings are in landscape format they are positioned so that the bottom of the painting is at the bottom of the case when it is upright.

After a journey the case is left to equilibrate at Gallery conditions for 24 hours. If the case has become cold during the journey there is a danger that condensation might occur on the cold contents if it were opened immediately.

## Packing case tests

The cases designed by Dristyle are not radically different from the cases previously used by the Gallery. They are still constructed from wood and use a compressible material for cushioning. An assessment of their performance is important to improve their design where necessary and to provide data, particularly for shock levels, from which a specification for packing cases for paintings could be derived. The latter function can only be achieved by comparison with results from other designs of packing case and we hope that this information will become available in the future [7].

**Table 1** Standard sizes of frames and cases and weights of cases made from phenolic-coated (PC) and double-faced-aluminium (DFA) plywood.

| | **Standard frame sizes** (mm) | **External dimensions of standard cases** (mm) | **Weights** (kg) | |
|---|---|---|---|---|
| | | | PC | DFA |
| 1 | 680 × 555 × 125 | 810 × 685 × 230 | 18 | 24 |
| 2 | 940 × 740 × 125 | 1070 × 870 × 230 | 22 | 30 |
| 3 | 1200 × 925 × 125 | 1330 × 1055 × 230 | 26 | 36 |
| 4 | 1460 × 1110 × 125 | 1725 × 1385 × 315 | 82 | 106 |

In addition to recordings made during journeys a series of controlled tests were designed.

Two cases were tested [8]: a Style 1 case of the second standard size, and a Style 2 case of the largest standard size. For all of the tests (except the waterspray) the cases contained framed canvases. The paintings were not glazed and a backboard of 5mm hardboard was attached to the back of the frame with screws. The paintings were not wrapped, nor was any silica gel placed into the cases. They were placed face-up in the cases. A detailed description of the tests and their results is reported elsewhere [9]. I shall only give a summary in this article, along with suggestions for improvements where applicable.

*Environmental tests*

The cases were fitted with temperature- and RH-recording devices and were placed in a cold chamber in which the temperature was rapidly reduced from approximately 15°C to −10°C. After internal conditions had stabilized they were returned to an external ambient temperature of 15°C. The cases were then placed in a hot, humid chamber operating at 40°C and 95–100% RH. After internal conditions had stabilized they were returned to the ambient temperature of 15°C.

The temperature in the Style 1 case took approximately 8½ hours to fall from 15°C to −10°C and about the same time to rise from 15°C to 40°C. The Style 2 case took approximately 13 hours to change over the same intervals. The total RH changes, for both cases, for both the temperature changes of 25°C was 13% RH±1% RH. The RH rises as temperature rises and falls as temperature falls, as predicted by Garry Thomson [10]. The seal on both cases seems efficient since the humid air at 95–100% RH in the hot, humid test does not appear to enter the cases.

These results show that the thermal insulation of the cases is surprisingly poor. Other foams do not have significantly lower thermal conductivity but the insulation of the case could be improved by using a thicker lining of the foam. However, the changes in RH recorded during the tests are not excessively great, neither do they occur very rapidly and so the improvement in thermal insulation is not a priority. Silica gel can be used to limit the RH changes further and enclosing the silica gel within Polythene wrapped around the painting will reduce the volume of air that the silica gel buffers. These results indicate that condensation will not be a problem even if the temperature in the cases falls below the dewpoint. However it might occur if a case were opened in Gallery conditions when the contents are very cold. This emphasizes the importance of not opening a case until after 24 hours of equilibration in Gallery conditions.

It was not possible to do a controlled test on the effects of pressure on the conditions within the case. The pressure may drop to 75% of the ground level value in an aircraft at cruising altitude. We may speculate that while an aircraft is gaining altitude air will be drawn out of a case in order to equalize pressures and on landing air will be forced in. Since the RH in an aircraft during flight becomes almost immeasurably low, any air exchange with a case may affect the RH inside it. Recordings made during flights will show if this is a problem.

*Waterspray test*

Both cases were stood on their standing-edges and were sprayed with droplets of water which were equivalent to rain falling at 200mm per hour. The droplets were falling at approximately 45° to the vertical. This test represents the heaviest rainfall which may last for more than a very brief period, possibly up to one hour, in winds of 25–30 km/hour. The test was carried out for 15 minutes. It is possible that a case might experience these conditions if it were being loaded into a vehicle during a storm or if it were left standing outside. After spraying, the cases were left for 2 hours before examination. The water sat on the top of the cases and collected in the interlocking seal of the Style 1 case. Before the cases were opened this water was wiped away so that it would not be drawn into the cases when they were opened. The Style 2 case was completely dry inside but a small amount of water (too little to collect and measure) had entered the Style 1 case.

In the future Style 1 cases will be made with a lift-off lid and the same seal as the Style 2 cases. There will be the added advantage of doing away with the webbing restrainers which occasionally get caught in the seal of the case.

*Drop tests*

Accelerometers were fitted onto the two frames to measure $G$ values in the three principal axes of the cases. $G$ is the acceleration (deceleration) that the dropped object receives at impact, expressed as a multiple of the acceleration of the earth's gravity. The cases were dropped onto a 6mm mild-steel plate bolted onto a concrete block 0.46m thick.

The cases were dropped vertically from various heights onto their standing edge. One accelerometer was located at the centre of the frame member at the bottom of the case and the other at one corner of the frame. The Style 1 case was dropped from a maximum height of 90cm and the Style 2 case from a maximum height of 60cm.

The peak deceleration recorded by the accelerometers located at the corner of the frame was greater than that recorded by the accelerometer at the centre of the frame. The maximum $G$ was 75 when the Style 1 case was dropped from 90cm and 65 when the Style 2 case was dropped from 60cm.

By comparing the results with dynamic performance curves of 'Plastazote' for 25mm of foam it appears that the loading of the cushions is in the right order of magnitude, but only the foam blocks are efficiently cushioning the painting; the 'Plastazote' lining does not contribute to the cushioning to any extent.

The tilt tests confirmed these results. Both cases, standing upright, were supported horizontally at one end and allowed to fall freely from a maximum height of 60cm. This drop might occur if one end of the cases were dropped while it was being carried. The decelerations were recorded by an accelerometer mounted on the bottom corner at the end that was dropped. The $G$ values recorded were very similar to those recorded for the straight vertical drops from the same heights.

To improve the cushioning in the case, attention must be paid to the loading on the cushions to make sure that

the foam is working efficiently, and thicker cushions should be used. Since the majority of paintings require additional foam blocks in order to fit the standard size cases these are placed so that they are under the long edge of the frame at the bottom of the case, to improve the shock protection for drops onto the standing edge.

The cases were toppled from the upright position onto their lids and bases. Each test was repeated with the cases standing on 30cm-high blocks. This is the type of drop cases might experience if allowed to fall when carried on a fork-lift truck. The decelerations were measured by accelerometers mounted in the centre of the frame member at the top of the case and by a second mounted at one of the top corners. These test the cushioning power of the foam in the lid and the base.

There was little difference in the results between topples onto the lid and base and the decelerations were similar when the cases were standing on the 30cm blocks or on the ground. The Style 1 case experienced decelerations of between 90 and 115 and the Style 2 case between 95 and 145. These are disturbingly high values and are almost certainly a consequence of incorrect loading of the foam in the lid and base.

Unfortunately the relationship between G values experienced by a painting and damage is not known and anyway is almost certain to vary from painting to painting. We should note that the results recorded were from accelerometers mounted on frames and the G values experienced by the canvases would be less as the frames absorb some of the energy of impact. Nevertheless we should aim to reduce the G values as low as possible with an efficient shock protection system.

### *Vibration test*

Accelerometers were mounted on the frames of the canvases in the cases and a very light accelerometer was mounted in the centre of the two canvases. Vibrational resonance searches were performed with the cases in different orientations. The G values recorded by the accelerometers were plotted on response curves as the cases were subjected to sinusoidal vibrational input at frequencies increasing from 5 Hz up to 290 Hz. Principal resonances of the frame, with a magnification of 2.5 were recorded for the Style 1 case between 45 and 50 Hz. For the Style 2 case the principal resonances of the frame were between 30 and 40 Hz with a magnification of about 2. These results showed that there were no serious resonances of the frames at the vibrational frequencies encountered during transport.

However, the response curves recorded by the accelerometers mounted in the centre of the canvases showed a number of resonances of significant magnification. The principal resonance of the Style 1 canvas occurs at 50 Hz and has a magnification of 5.5. This represents a displacement of 2.5mm of the centre of the canvas where the accelerometer is located.

This is worrying since it seems inevitable that a canvas will vibrate during transport and it is not easy to see a way of preventing this without immobilizing the canvas. This emphasizes the importance of not allowing paintings to travel when there is any doubt about their structural stability.

**Figure 4a**
Style 2 case in tank for waterspray test.

### *Impact test*

An impact test was used to determine the relative strengths of phenolic-coated and double-faced-aluminium plywood. The test was devised to simulate the effect of a fork-lift truck tine on test samples that measured 750mm square. A fork-lift tine weighing approximately 35kg was suspended from a height of 4m above the base of the test samples. Impact position was about 200mm above the lower edge of the test sample. The tine was pulled straight back to a measured vertical height above its equilibrium position and allowed to free-fall to impact. The tine was raised and impacted in a succession of equal increments until the board was considered to be in an unserviceable condition. For the phenolic-coated plywood this was when both external veneers were split and for the double-faced-aluminium plywood when it was punctured.

The maximum recorded vertical drop heights above the equilibrium positions were as follows:

| | |
|---|---|
| Phenolic-coated plywood | 365mm |
| Double-faced-aluminium plywood | 930mm |

This indicates that the double-faced-aluminium plywood is approximately two-and-a-half times more resistant to impact than phenolic-coated plywood. The Style 2 cases are usually made in double-faced-aluminium

plywood since they are often handled by fork-lift truck and are more susceptible to rough handling as they are larger.

## Recording made during journey: National Gallery, Washington to National Gallery, London

In May 1983, Italian School, *Dead Soldier* (No.741) was transported from the National Gallery, Washington to the National Gallery, London. It had been loaned for the 'Paintings in Naples from Caravaggio to Giordano' exhibition.

A Style 2 case constructed from double-faced-aluminium plywood and lined with 50mm of 'Plastazote' was fitted with 25mm cushions for the painting whose dimensions are 2045 × 1403 × 114mm. Six 250g bags of silica gel were taped to the backboard and the painting was wrapped in a single sheet of Kraft paper. Kraft paper was used rather than Polythene because there was no room to include the temperature- and RH-recorder inside the parcel and we wished to record the effect of the buffering of the painting and the silica gel on the RH inside the case. Polythene would have isolated the recorder from conditions in the vicinity of the painting. A cavity was cut in the lining of the case and the solid-state memory, temperature- and RH-recorder [11] was secured in it with adhesive tape. The recorder was set to record every 15 minutes. Three shock detectors [12] were attached to the back of the painting. The most sensitive of these can detect shocks with a G value greater than 50. The painting was placed face-up in the case and orientated so that the bottom of the painting was at the bottom of the case when standing upright. The case was closed and padlocked and three shock detectors were placed on the base and three on the lid.

The closed case remained in the packing area of the National Gallery for two days. On the third day it was loaded into an 'Air-Ride' truck. The truck was air-conditioned (temperature control but no RH control) and fitted with a very efficient shock-absorbing suspension system. The journey from Washington to JFK Airport, New York took 5 hours. The case was unloaded and stood in the Flying Tigers shed for 6 hours. It was then moved by fork-lift truck onto a flat metal pallet on which it was surrounded by other cargo.

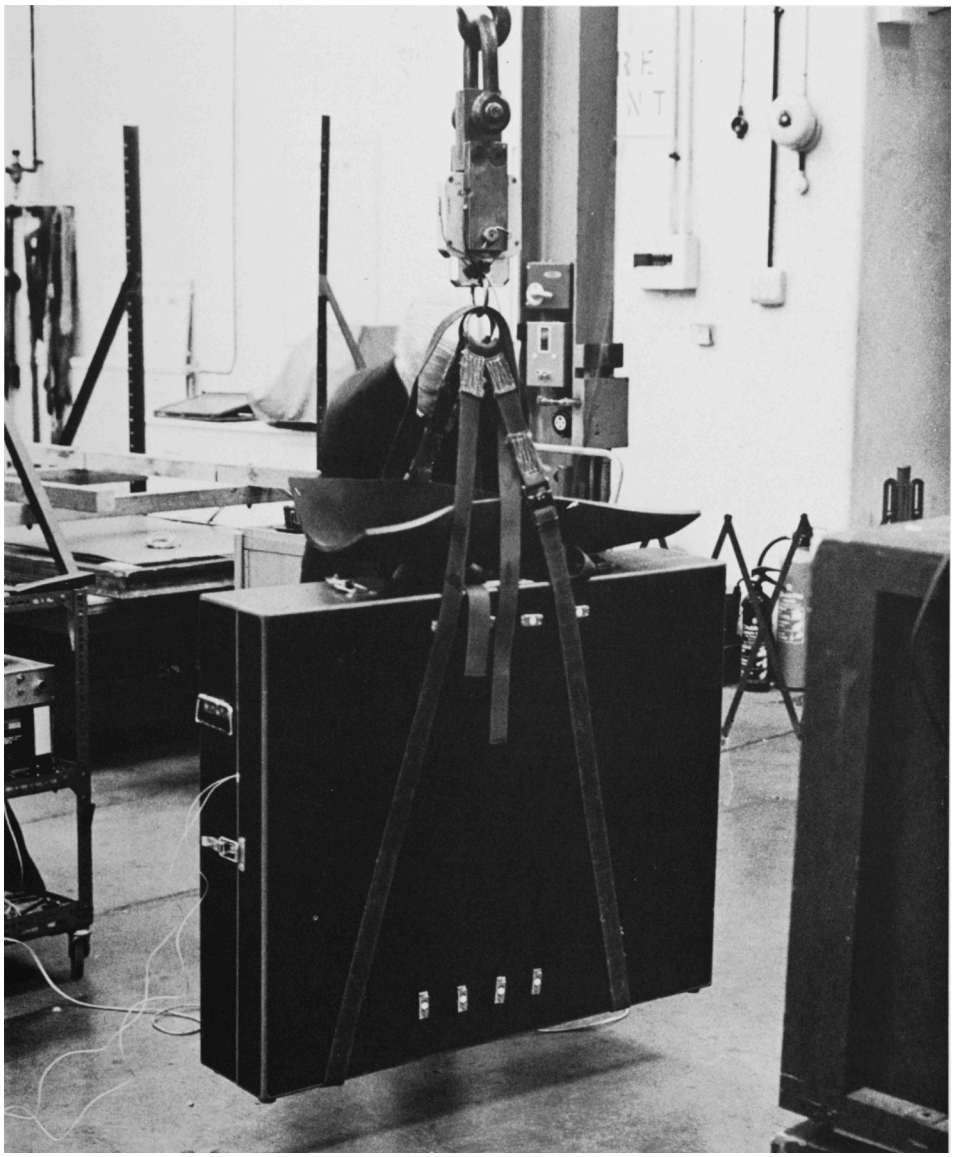

**Figure 4b**
Style 1 case in sling before vertical drop test.

When loaded the pallet was covered with a sheet of Polythene and a net was fastened over the whole load to prevent it from moving. The pallet was moved from the shed onto the runway and into the hold of a 747 cargo plane. The flight took 7½ hours and there was very little turbulence.

The pallet was off-loaded very quickly after landing at London, Heathrow and taken into the Flying Tigers shed. The case was taken off the pallet and cleared by customs within 2 hours. The case was loaded onto a furniture removal van and returned to the Gallery in an hour.

As many readings of temperature and RH outside the case were made during the journey as possible. These are included on the recording of temperature and RH within the case shown in Fig.5. The temperature within the case follows external conditions with a short time lag. The relative humidity remained fairly constant (46%±3%) inside the case throughout the journey. During the flight the RH in the hold dropped to below 10% but there is no sign of a significant drop in RH inside the case. This indicates that for this flight low pressure at high altitude is not adversely affecting the conditions inside the case.

None of the shock detectors registered during the journey and therefore neither the case nor the paintings were subjected to *G* shocks as large as 50.

## Instrumentation

### *Solid-state memory recorders*

For recording temperature and RH in packing cases during transport we are using recorders [11] which store the digitized readings in a solid-state memory. The recorder operates within the temperature range −5° to 35°C and within the RH range 0–100%. It can store 1024 readings (512 each of temperature and RH). Its small size, 50 × 90 × 200 mm, makes it convenient to use in a packing case. After the recording is complete the readings are transferred to a computer in the Scientific Department for print-out and analysis. The recorder will take readings at intervals of 15, 30 or 60 minutes.

### *Shock detectors*

We are using two types of shock detector, both of which can be attached to the outside of cases or the backboard of paintings to register impacts.

The first [12] consists of a glass capsule containing a porous white material separated from a red-coloured liquid. When the capsule experiences a shock greater than a certain *G* value the glass wall breaks and the red liquid colours the white material. The capsules are mounted on brightly coloured warning labels and the colour of the labels indicates the sensitivity of the indicator. They are available in four sensitivities. The glass wall breaks at greater than the given *G* values for the colours as follows:

| | | |
|---|---|---|
| Yellow | > | 25*G* |
| Red | > | 50*G* |
| Orange | > | 75*G* |
| Green | > | 100*G* |

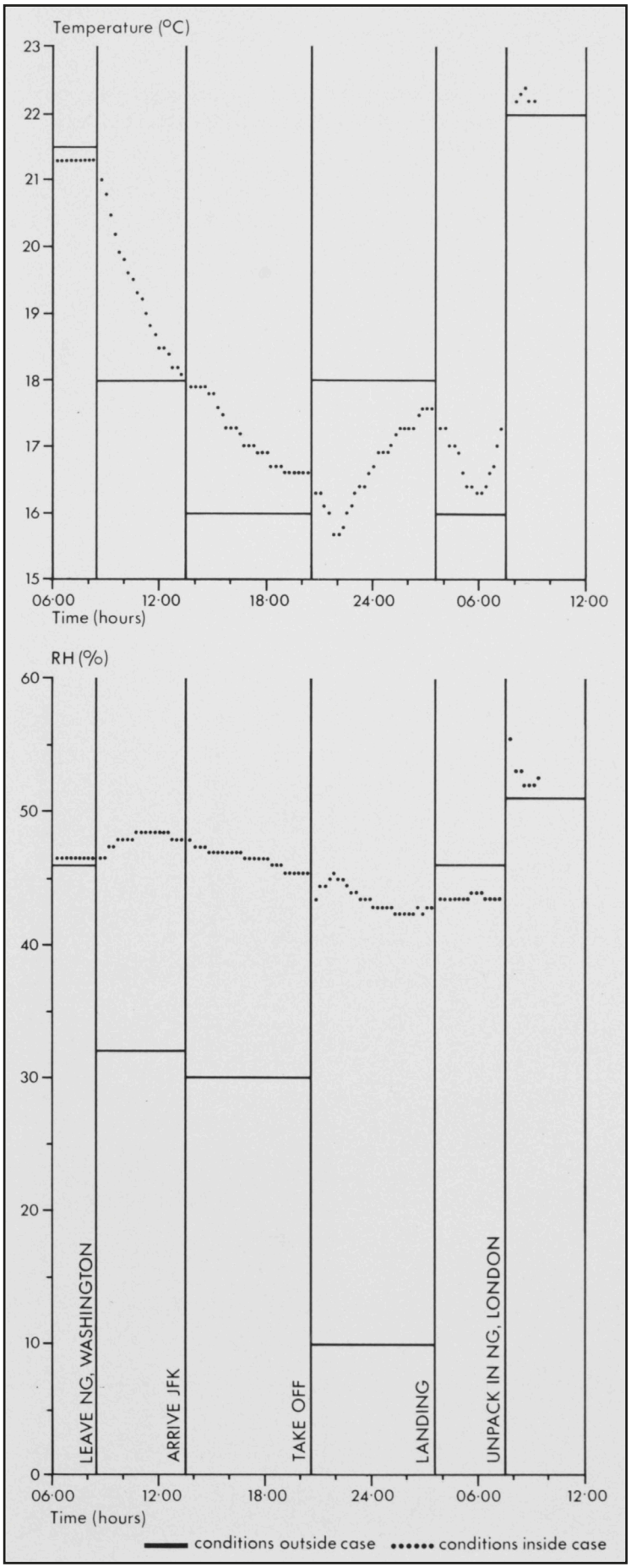


**Figure 5** Temperature- and RH-recording during journey from National Gallery, Washington to National Gallery, London.


**Figure 6** (Behind right) Freeman Enercon temperature- and RH- solid-state memory recorder. (Behind centre) Memory transfer unit to output readings from recorder to computer. (Behind left) Test/display unit to check function and battery of recorder. (Foreground right) Drop (N) Tell Impact Indicators. (Foreground left) 3M Shockwatch.

Unfortunately once these have registered they cannot be re-used.

The second type of indicator [13] is re-usable and is also directional. These consist of two springs inside a small plastic holder containing a weight. When a certain *G* value is exceeded in the direction in which the indicator points, the weight trips the spring and a red arrow becomes blue on the front of the indicator. The *G* values at which the indicators register are 5, 10, 15, 25, 50 and 100. They are easily reset. Three are needed to register shocks in each of the principal axes of a case.

During the drop tests previously described the shock indicators which were located on the outside of the cases did not necessarily register when the shock measured on the frames were greater than the *G* values they were supposed to indicate. Their use as monitoring devices should therefore be cautious, particularly when used as warning devices on the outsides of cases. Paintings may experience larger shocks than they register.

## Conclusion

The Dristyle Products Ltd cases are a significant improvement both in their performance and in their versatility over the cases previously used. The four standard sizes have proved to be suitable for the majority of smaller paintings loaned since 1982, although occasionally paintings with unusual proportions (long and thin or square) have been requested for loan and a case has been tailor-made.

The cases have stood up well to handling during transport and their finish protects them to a great extent from the wear and tear that shows on painted or untreated wooden cases. Although, to our certain knowledge, there has been at least one serious dropping of a case, on examination of the painting and frame there was no immediate evidence of damage. Indeed, so far, all paintings that have travelled in the new cases have arrived at their destinations with no visible signs of damage. However, that is not to say that deterioration will not appear in the future as a result of transport.

We must not be complacent. The controlled tests show that there is room for improvement. The thermal insulation could be made better by using a thicker lining of foam. We will specify this for cases which are likely to experience extreme temperature conditions. All Style 1 cases will be made with lift-off lids and a Style 2 seal to ensure that water cannot enter the cases. The cushioning in the lid and base must be improved and more attention paid to the loading of all cushions and their thickness to reduce the *G* values experienced by the paintings.

The most worrying problem demonstrated by the tests is the effect of vibration. The size of the resonances recorded by the accelerometer placed in the centre of the canvases is large. Although no research has been carried out on the relationship between vibration and deterioration in paintings we can intuitively realize that if a canvas vibrates with a significant amplitude the canvas will stretch and relax at the frequency of the forcing vibration. This will result in stresses building up in the painting, particularly where the canvas 'turns-over' the edge of the stretcher, and also in the paint and

ground films. This could result in the weakening of the structure and possible paint loss. We must look at ways of reducing the transmissibility (the ratio of the energy of the induced vibration to the input vibration) of packing cases. Work in progress in the USA [14] may help us with this.

Many museums all over the world are now interested in the improvement of packing cases and this becomes increasingly important with the ever-growing trend for travelling exhibitions.

## Acknowledgements

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3. GORDON, J.B., 'Packing of Michelangelo's "Pieta"', *Studies in Conservation*, **12** (1967), pp.57–69.
4. PADFIELD, T., ERHARDT, D. and HOPWOOD, W., 'Trouble in Store', in *Science and Technology in the Service of Conservation*, N.S. Brommelle and Garry Thomson (eds.), IIC Washington conference (1982), pp.24–7.
5. Dristyle Products Ltd is a subsidiary of EPS (Research and Development) Ltd. (Dristyle Products Ltd, 152, Staplehurst Road, Sittingbourne, Kent ME10 1XS, Tel. Sittingbourne (0795) 79246.)
6. 'Plastazote' is manufactured in the UK by BXL Plastics Ltd. (BXL Plastics Ltd, ERP Division, Mitcham Road, Croydon, Surrey CR9 3AL, Tel. 01–684 3622.) The density of the 'Plastazote' is 40–50kg/m and its code number is PO 56 (Black). 'Ethafoam' is a similar closed-cell polyethylene foam manufactured by Dow Chemicals in the USA.
7. The shock and vibration tests were designed after discussion with Stephen Hackney and Timothy Green of the Tate Gallery, London to allow comparison between results. The results of the tests on a Tate Gallery packing case are described in: GREEN, T. and HACKNEY, S., 'The Evaluation of a Packing Case for Paintings', *Preprints of ICOM Committee for Conservation*, 7th triennial meeting, Copenhagen (1984), 84/12/1.
8. The tests were carried out by EPS (Research and Development) Ltd following a procedure drawn up by the National Gallery and Dristyle Products Ltd. The vibration test was sub-contracted to Marconi Avionics Ltd. We thank Dristyle Products Ltd for their assistance with the payment for this testing.
9. STANIFORTH, S., 'The Testing of Packing Cases for the Transport of Paintings', *Preprints of ICOM Committee for Conservation*, 7th triennial meeting, Copenhagen (1984), 84/12/7.
10. THOMSON, G., 'Relative Humidity Variations with Temperature in a Case Containing Wood', *Studies in Conservation*, **9** (1964), pp.153–69.
11. A Freeman Enercon TM1H recorder was used. (Freeman Enercon Ltd, 66/68 Hills Road, Cambridge CB2 1LA, Tel. Cambridge (0223) 315432.) These recorders are also available from Grant Instruments (Grant Instruments (Cambridge) Ltd, Barrington, Cambridge CB2 5QZ, Tel. (0763) 60811). They also make Squirrel solid-state recorders. For a description of both of these types of recorder see: STANIFORTH, S., 'Solid-State Memory Recorders', *UKIC Conservation News*, 22, November (1983), pp.11–12.
12. 3M Shockwatch (from Parafix Tapes, Unit 4, Meadow Row Industrial Estate, Worthing, West Sussex, Tel. (0903–205) 334).
13. Drop (N) Tell Impact Indicator (from Costerwise Ltd, 16 Rabbit Row, London W8 4DX, Tel. 01–221 0666).
14. Private communication with Paul F. Haner, Conservator, Worcester Art Museum, referring to work at the Philadelphia Museum of Art in conjunction with Dow Chemicals.