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Packing: An Updated Design, Reviewed and Tested

Ann Stephenson-Wright and Raymond White

Packing: an update

Ann Stephenson-Wright

Introduction

In an earlier article [1] Sarah Staniforth worked through the general requirements of a packing case for the transport of paintings, explained the derivation of the National Gallery's design and the performance tests carried out on it, and gave a detailed account of the behaviour of the case in real life during one particular, though fairly typical journey. The original design has now been updated and this article compares the results of a new series of tests with those carried out on the earlier case. In addition, a report is made on results of an assay carried out on the packing case to gain some idea of the quantities and nature of organic vapours present in the sealed environment. Although the National Gallery's design description specified water-soluble adhesives and inert gas blown plastic foams, reports that odours could be detected upon opening newly constructed cases suggested the need for such an examination. The packing cases which the National Gallery has used regularly since 1982 were designed and manufactured to the National Gallery's own design description [2] and we have built up a stock of thirty-six such reusable cases. Recently, however, there have been occasions when no suitable cases have been available from our stock and we have then leased a new container from the manufacturer. The manufacturers have based the design of the lease containers on that of the National Gallery's original design description, but as a result of the conclusions drawn from previous tests [3,4], and also in response to the requirements of other users [5] certain features have been updated. It was therefore decided that the tests be repeated, not only to check that the performance of the updated design maintained or bettered that of the stock cases, but also to add to the data on case performance which is building up world-wide and from which, it is hoped, a useful and practicable packing-case specification can be derived.

Description of the revised design

One of the main conclusions to come out of the previous report was that thermal insulation could be improved, and it is in this area that the main difference between the two case types lies. However, a compromise needs to be struck between better insulation (which inevitably means thicker insulation, as the materials used are already very efficient) and the resultant increase in size of the case. A larger case is a more unwieldy case, one that exacerbates problems of handling and transport which can pose as serious a threat to the wellbeing of the contents as any change in the internal temperature. In this case the extra insulation produces a moderate and reasonable increase in depth, which has, in fact, the added advantage of extra stability on the standing edge, so reducing the chance of the case falling onto either of the large faces (Fig.1). The outer container of the case was similar to that previously tested (one of our Style 1 stock cases) except that it was constructed from plywood faced on both sides with aluminium, rather than phenolic-coated plywood, assembled using the polyurethane elastomer Dripak process [6]. The internal lining comprises a minimum 100 mm thickness of thermal insulation. The extra insulation is achieved by increasing the 'Plastazote' lining of the original design from 25 mm to 50 mm and adding between this and the outer wall a combination of slab fibreglass and expanded polyethylene. To improve the performance in the drop tests a different cushion material had to be used, and so the 'Plastazote' was replaced with polyurethane polyester for the pads, and for the lining in the side walls where it acts in the dual role of cushion material and insulator.

Packing case tests

The tests were carried out on a Dripak Fine Art Container, size 20 (1180 mm × 960 mm × 425 mm) using the unglazed frame and prepared canvas that had been used in the previous test [7]. The picture frame was fitted with accelerometers to monitor shock levels in the two principal axes, and a platinum resistance temperature detector and a humidity sensor to measure environmental changes. As before a cold test to −10°C and a hot humid test to +40°C were carried out. Drop tests were conducted with vertical impact onto the travelling base from 15, 45, 60 and 90 cm, and topple tests from the standing base onto each large face, and from one end onto the back face, both with the case standing on the ground. The topple test from 30 cm above ground was dispensed with as previous results had shown the shock sustained to be very little different from that experienced when toppled from ground level. This group of tests was followed by a waterspray test.

As the previous article concluded, the most worrying problem is the effect of vibration. One method of investigating this is to identify the natural frequency at which the container vibrates, isolate the resonance frequencies and establish by how much an input vibration (for example from a vehicle) will be amplified at these frequencies. This can conveniently be done by strapping the case to a test bed and measuring the vibration experienced inside the case as the test bed oscillates at a regular and increasing rate across the relevant range of frequencies.

Results

Environmental tests

The temperature took approximately 20 hours to fall 25° from 15°C to −10°C, and about the same (in fact 18 hours) to rise 25° from 15°C to 40°C. This compares with a stabilization time under the same conditions for the earlier case of 8.5 hours. Another means of expressing thermal conductivity is the concept of half-time, where, in this case, half-time is the time taken for the temperature sensor on the frame to register a temperature half-way between the temperature inside the case at the start of the test and the steady external temperature. Half-time is an increasingly widespread method of representing thermal conductivity data and is particularly useful because, for a given thermal barrier and conditions where the external temperature is instantaneously changed, it generally has a constant value, regardless of the starting temperature. This facilitates the direct comparison of results from tests with quite different ambient and test temperatures. In this case the half-time for the container was 6 hours, both for the cooling and the heating period.

Drop and topple tests

Two accelerometers were used to measure the maximum force on impact, one located at the centre of the frame and one at the corner. For the vertical drop tests these were located at the bottom of the frame, and at the top for the topple tests. For the vertical drop on to the standing edge from 60 cm the maximum force experienced was 37 G, recorded at the centre of the frame, and 47.5 G when dropped from 90 cm. When the case was toppled onto its lid from standing on its base the maximum deceleration experienced was 22.5 G, but onto its back face this rose to 32.5 G. The topple from the end onto the back face registered 21 G at the frame centre and 41.5 G at the corner. This last topple was conducted for comparison purposes, as in use the case should never stand on any edge but the base. The case was opened and inspected after each test and no visible damage had occurred to the picture frame, canvas or internal cushioning.

Figure 1 National Gallery Standard (Style 1) case (left) next to a 1987 Lease Standard case (1500 × 1250 × 430 mm).

Waterspray test

A waterspray test was carried out before the environmental and drop tests and, as before, showed that no water had penetrated. However, the waterspray test carried out at the end of the testing was disappointing as approximately 100 ml of water had leaked inside. This was due to the seal having been incorrectly repaired at the points where the instruments used in earlier tests had been inserted, thereby breaking the seal's continuity. It was obvious on inspecting the case that it was these damaged points which had provided a channel for the water to enter. The waterspray test was repeated when the container seal had been acceptably repaired, and as with the initial test on the unpierced case, no water penetrated.

Vibration test

Sinusoidal vibration was applied at two severities; from 5 to 160 Hz at a constant peak acceleration of 0.3 G ± 0.1 G, and from 5 to 10 Hz at ±5 mm displacement then 10 to 160 Hz at 2 G ±0.2 G. Each vibration severity was applied in three orthogonal directions and the maximum transmissibility (that is, the amount by which the input vibration is magnified), and frequency at which it occurred was measured by the accelerometers positioned as for the shock tests.

With the case upright on the test bed, for a peak acceleration of 2 G the principal resonance of the frame occurred between 12 and 14 Hz, with an amplification ranging from 1.6 to 2.2. However, with the lower input force of 0.3 G, the resonance occurred at a higher frequency: 26 to 30 Hz, and the amplification was slightly higher at between 3.0 and 3.7. With the case flat on the bed the maximum transmissibility was 3.9 at 32 Hz at 2 G input, rising to 5.7 at 37 Hz at 0.3 G. All these recordings were taken on the frame. Only one set of readings was taken on the canvas and this with the case lying flat on the test bed. For an input acceleration at 2 G the point of resonance was close to that of the frame, 36 Hz, but the amplitude was increased to 23, while at 0.3 G acceleration an alarmingly high transmissibility of 60 was recorded at 45 Hz.

Conclusions and comparisons

The elastomer seal on the cases is a major design feature in that, when correctly made, it provides not only a truly watertight environment for the work of art but also improves the maintenance of a micro-climate. However, it is clear from the waterspray tests that if it is damaged the seal cannot work effectively, and it is therefore important that the cases are carefully maintained and checked before each journey.

The updated design performed significantly better

than the earlier design in the environmental tests, and also in all the shock tests where, although we cannot put a precise numerical value on the fragility of a painting (which will anyway be different for every painting), the results were below the maximum fragility factor for delicate packaged articles [8] (see Table 1).

To be of any real long-term value the tests and results need to be compatible with data collected by other researchers in this field, hence the vibration test is slightly different to that run previously. With the case oriented vertically and input acceleration at 2G the actual amplification is less, although the point at which the principal resonance occurs has now moved into the frequency range where the most severe vibrations in the various types of transport are known to occur [9] (an inevitable consequence of using softer cushioning to improve shock protection). However, this level of input excitation is much higher than that which recent research [10] has indicated to be normal in road transport, and the new tests at 0.3G would seem to approximate better to the real situation.

Because foam cushioning in general behaves in a non-linear fashion with respect to energy absorption, it is expected that as the level of input excitation changes (for example, in our case from 2G to 0.3G) so the point of resonance will change. The results show that the resonant position is moving out of the critical range for road vehicles the nearer we get to simulating the low input acceleration of the real situation. Unfortunately, both the point of resonance and the amplification depend on the mass of the object which is creating the load on the cushioning. This means that the results strictly apply only to a particular case at a particular loading, and it is difficult to make any inference about the design in general, except that it is important to load the foam correctly, for which we need to know the weight of the painting and frame — information not usually available. Loading also explains why the results for the horizontal orientation were so different: the foam in the larger faces was probably underloaded compared to that around the edges, so changing the characteristic response of the foam. Underloading will also mean that the optimum shock protection is not being achieved. The most disturbing result, as before, is the amount of vibration experienced by the canvas (but it must be remembered that the test orientation will be the worst situation, with the input vibration at right-angles to the plane of the canvas). Still, even allowing for the heavier accelerometer (which will tend to increase the readings) this is high reading and a strong argument against ever transporting paintings flat. Even when transported vertically, if the case is strapped to the side of the vehicle the canvas will inevitably experience vibration in this direction, although to a much lesser extent. However, it has been shown that both glazing and backing a frame with stiff material will significantly suppress the canvas vibration [11]. In practice, the input vibration is not a sustained sinusoidal disturbance at all, but totally random, and no design criteria exist to correlate the two. Finally, there is still no way of relating the vibration or shock experienced by a painting to any damage observed. This means that design solutions still have to address the problem at the intuitive level, by minimizing both shock and vibration as far as is reasonably possible. Perhaps a more fruitful line of investigation will reduce the vibration that the case experiences (rather than expecting the case to bear the full burden of attenuating the vibrations) by encouraging the use of the new generation of air-ride vehicles with well-damped suspension, and developing vibration-damping materials that can be incorporated into the body of the vehicles.

Because a painting is at its most vulnerable when off the wall and travelling, those who commission cases have a grave responsibility; yet the design of a container requires knowledge and understanding of complex issues [12–15], quite apart from any environmental considerations. Truly informed and objective choices can only be made if the risks have been rigorously assessed and if comprehensive and universally compatible performance data for containers is routinely available. That ideal situation is in the future; until then, being always alert to the gaps in our knowledge, and aware of the compromises forced on us, we must choose our cases as best we can.

The results presented here show that the level of protection provided for National Gallery paintings on the move has increased. Also, by adding to the data that is being collected internationally, it is hoped that the results will hasten the derivation of a true technical specification: only when parameters have been established will we be able to compare designs consistently and fairly, or systematically assess the balance between cost, ease of use and level of protection.

Table 1 Comparison of the results of environmental, shock and vibration tests conducted on cases of the National Gallery Standard and the 1987 Lease Standard designs.

	Case type	
	National Gallery	**1987 Lease Standard**
Environmental test: (Time taken for temperature to equilibrate)	8.5 hours	19 hours
Drop test from:		
60 cm	65G	37G
90 cm	75G	47.5G
Topple test from base:	90–115G	22.5–32.5G
Vibration test: (case vertical, input acceleration 2G)		
Principal resonance	45–50Hz	12–14Hz
Amplification	2.5	1.6–2.2

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Packing: the chemical environment

Raymond White

Over the last few years, much attention has been devoted to packing case design and the requirements for adequate protection of easel paintings during transportation not only within a particular country, but also over considerable distances throughout the world. With the development of modern, synthetic polymers for padding and newer combinations of materials for structural elements, lighter and stronger cases have been designed. In addition to the conventional requirements of the system to protect against shock and vibration, water and dust, greater attention has been given to more effective ways of providing a local environment able to dampen response to changes in external environmental parameters such as temperature and humidity. Thus in addition to mechanical considerations, an effectively designed case should have as low a rate of exchange of air between its interior and the outside atmosphere as possible.

Under such circumstances it becomes clear that far greater attention must be given to the materials of construction of such a 'sealed' system. Organic vapours produced by sealants, residual monomers and plasticizers dispersed in organic polymers used as shock-absorbers and packing, could diffuse out into the sealed environment. During the course of storage it would then be possible for the varnish or painted surface to absorb organic vapours. The long-term result might be softening and swelling of the varnish or paint, thereby rendering the paint more sensitive to solvent action. Absorption of ketonic and aldehydic components would provide potential centres for enhanced photolytic action, whilst amine-like components would increase the potential for the formation of coloured Schiff's base components and the formation of amine salts. Examples have been encountered of the uptake of plasticizer into organic layers during storage [1].

On average, it is unlikely that easel paintings in transit would remain in this sealed environment for more than one week to ten days. In view of this it might be supposed that organic vapour action would be minimal during such a relatively brief period. Nevertheless where components with considerable ability to swell cross-linked drying oil films or reactivity were present in relatively high concentrations, the seeds of damage could be sown over just such a period. As a result it is desirable to gain some idea of the overall amounts and general nature of the components that might diffuse into the closed environment of a new packing case that has been allowed to remain undisturbed, but sealed in order to reach an equilibrium. This would represent the limiting condition, and as the case ages, the rate of diffusion of trapped components should drop as their concentrations within the bulk of the packing or structural fabric decrease.

Over the last two decades, more attention has been given to the characterization of organic vapours evolved from a variety of household materials both synthetic (paints, floor adhesives) and natural (various wood

products). Methods employing charcoal, molecular sieve or Tenax polymers to trap organic components — so concentrating them prior to analysis — have been used [2,3].

Experimental

The Dripak case selected was of external dimensions: 1200 mm × 950 mm × 430 mm. Its construction has already been outlined in the introductory section of this article. The volume of air within the central cut-out of the case was estimated to be 0.1363 m^3.

Trapping and de-sorbing equipment

A $\frac{1}{4}$ in. o.d. × 15 cm length of glass-lined metal tubing was chemically cleaned in an ultrasonic bath with Decon 90. Each end was fitted with Swagelock reducing unions ($\frac{1}{4}$ in. pipe to $\frac{1}{8}$ in. pipe) using polyimide ferrules. To one end was fitted a 7.5 cm rounded-end syringe needle, normally used for on-column capillary injection. This was accomplished by means of a $\frac{1}{8}$ in. polyimide ferrule pierced longitudinally with a 1 mm hole for the needle. The injection end of the column was loosely packed with a $\frac{1}{2}$ in. plug of silylated quartz wool. The glass-lined metal tube was then filled with Tenax pellets to within $\frac{1}{2}$ in. of the end union and another $\frac{1}{2}$ in. silylated quartz wool plug was installed. A coiled length of chemically cleaned $\frac{1}{8}$ in. copper tubing was connected via a polyimide ferrule, which in turn was connected either to a small piston vacuum pump or to a pure helium supply fitted with flow controller and pressure-control by-pass valve. The outer surface of the glass-lined tube was wrapped with a heat-transmitting foil as shown in Fig.2, from the front portion of the union fitted with on-column injection needle to within $\frac{1}{2}$ in. of the union at the other end. A fine thermocouple, type K was incorporated between the first and second layer of foil. Three further layers of foil were applied, to give a uniform, heat-distributing bed for the heat source. Heating tape (104 watts, 120 volts) was wrapped uniformly over the metallized tape from the front of the injection-end union. Care was taken to avoid overlapping of the tape turns, with consequent production of local hot-spots. Two layers of metallized tape were applied over the heating tape, the former being suitably earthed and then several layers of insulating polyimide self-adhesive tape. A further type K thermocouple was sandwiched after the fourth layer of polyimide to check that the outer surfaces of the assembly did not become excessively hot. The heating tape was connected to a proportional temperature control unit regulated by one of the type K thermocouples placed below the heater. The other was connected to a compensated digital temperature read-out module. Preliminary trials with a thermocouple inserted inside the desorbing tube suggested that the internal temperature was in the region of 12°C below the indicated and 'set' temperature on the external thermocouple and control.

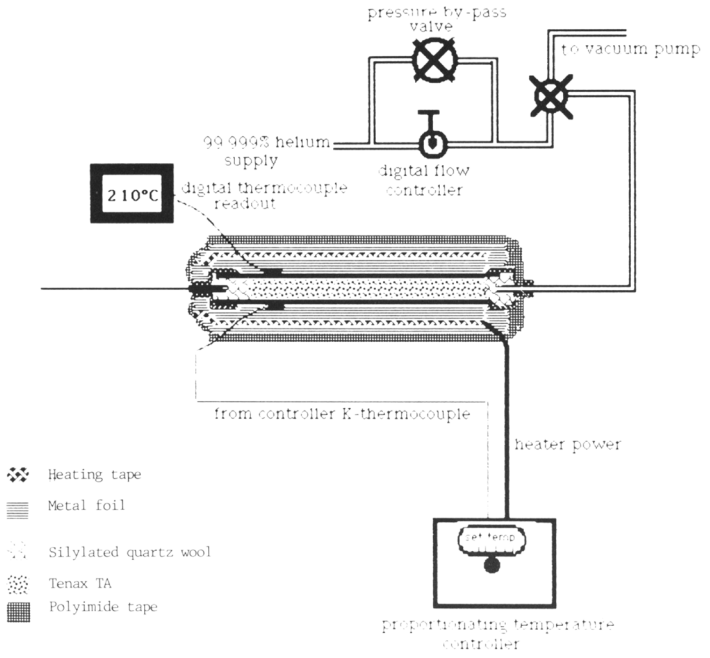

Figure 2
Diagram of construction of trapping unit.

Preliminary conditioning of sorbent and trapping of volatiles

The trapping unit was connected to a 99.999% purity helium supply via a digital flow-controller and was purged for two hours with helium at a flow rate of 6 ml per minute, to remove oxygen. The unit was then heated by 50°C steps allowing periods of twenty minutes to elapse at each stage, when the set temperature was reached. During the course of this procedure, the proportionating device of the controller was adjusted to minimize over-shoot and to minimize the time taken to reach a stable plateau. This was continued until a set temperature of 290°C was attained and then the unit was left to purge for a period of two hours. The system was then allowed to cool to ambient temperature, whilst continuing the purge with helium gas. A blank run was performed on the desorbed Tenax unit by switching the helium supply to pressure by-pass with a pressure of 0.37 bar and inserting the needle through the septum of the on-column injector and allowing 4' minutes for the system to stabilize. The column used was 25 metre, 0.5 mm bore quartz capillary column with a methyl-silicone bonded phase. The initial column temperature was approximately 22°C (ambient) and during de-sorbing of the trapping column a cold air blower was trained on the first part of the column. The temperature controller for the Tenax unit was set to 290°C (8 minutes were allowed to elapse, before removal of the trap). The column was programmed at 5°C per minute to 290°C, held for 10 minutes. The mass-spectrometer was programmed to scan at 1 decade per second from mass 600 to 28, electron impact mode, 70 electron volts, trap current 100 μA. Only some residual traces of perfluorokerosene fragments and traces of silicone trimers and tetramers, from the septum and catalytic/thermal decomposition of the column stationary phase were observed.

A plastomer seal on the edge of one of the sides of the case was pierced with a sharp needle. It had been intended to withdraw aliquots of the air from within the case by merely inserting the probe needle through the pre-pierced plastomer seal. However, lest the air sampled only 5 cm from a corner should be non-representative and to avoid blockage of the needle by packing, it was decided to insert chemically cleaned $\frac{1}{16}$ in. o.d. stainless steel pipe into the centre of the case and insert the sampling needle within this, using a temporary Teflon washer to ensure an adequate seal. In addition, on attempting to draw air from the case through the vapour trap, due to the hermetic nature of the closure, the sampling pump was unable to maintain an adequate flow by virtue of a partial vacuum. The case was punctured in a plastomer seal, diametrically opposed to the sampling point. A short guard trap of de-gassed Tenax TA was fitted to this vent to remove the possibility of the introduction of vapours from the surrounding laboratory. At the end of the series of experiments, the efficacy of this guard system was tested by holding a small ampoule of diethyl ether near the inlet of the vent and checking for traces of this in the desorbed effluent from the main trap. None could be detected.

The packing case, without a picture, having been freshly constructed and left undisturbed for a period of three weeks was prepared for test. A sample of approximately 523 ml of air from the case was drawn through the trapping unit at about 8.5 ml/min. over a period of about an hour. The pump was switched off, the unit removed, the helium supply (with pressure by-pass valve open) connected and the injection needle inserted fully into the on-column injector. The procedure outlined above was followed on each occasion.

Results and discussion

This study was not intended to be exhaustive, but merely to give some order of magnitude to the amounts and possible nature of volatiles that might be found in the sealed atmosphere of a freshly constructed protective case. It is clear that the overall quantity of organic components in this particular instance was low. The synthetic and natural materials used in the final construction would appear to have contributed surprisingly little to the final environment. In part this must be due to the use of well-cured (that is, with little residual monomer) polymers, low in volatile plasticizers and material 'foamed' by inert gas blowing, rather than by catalytic production. The silastomer seal was chosen primarily for its watertight properties, but is understood to be gas-permeable. Table 2 gives tentative component identifications with an estimate of the concentrations present in the case atmosphere after three weeks of equilibration.

The figures given in Table 2 are only orders of magnitude, based on the assumption that the response factor for the components do not differ markedly from that for acetic acid, used as standard. Identification was based on computerized library search, except in the case of formaldehyde, whose spectrum seemed to have little other than a predominant mass of 30 after removal of background. Following measurement, the case was opened fully; it was then re-sealed and left undisturbed for a further two weeks, before a second set of measurements was carried out. No organic components of any consequence could be detected, save traces of acetic acid, which seemed to be at a level of only 1 or 2% of that in the case at the first sampling.

It would seem reasonable to suggest that the quantities of organics found in this case are very low and that if the case were to be left for a few days in the fully open state, in warm surroundings with a regular air-change, no harm would come thereafter to a painting left sealed in the container for several weeks.

Table 2 Components detected in Dripak case.

Scan no.	M^+	B^+	Identity	Estimated concentration µg/m³
02	30	30	formaldehyde	0.4
36	44	44	acetaldehyde	4.6
38	58	43	2–propanone	2.2
43	60	45	acetic acid	5.2
104	86	57	pentan–3–one	0.2
147	(116)	57	1–methylethylpropanoate	0.1
176	74	74	propanoic acid	4.6
239	?	104	aromatic (styrene-derivative?)	~0.5

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