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Learning through industrial archaeology: the Rocket *locomotive project*

Introduction

In the quest for greater understanding of the history of engineering and technology, the artefacts in the world's museums of science, technology and industry provide a most important resource. A thorough survey of these artefacts, together with historical and technical research surrounding their history, can advance our knowledge of the development of materials, manufacturing methods and maintenance practices. The importance of this resource is apparent because engineers and technologists often failed to record their approach to design and manufacturing methods, and their understanding of materials. Furthermore, the accumulated knowledge and skills of the tradesmen were rarely recorded, being transmitted from master to apprentice, each generation developing the skills of its forebears.

Recent calls to pursue a greater understanding of artefacts, through survey,[1] have led to several research studies in the 1990s, some leading to conservation and restoration projects by the authors, summaries of which have recently been published.[2] The most comprehensive of these studies was carried out by the authors at the National Railway Museum in York during 1999, on George and Robert Stephenson's *Rocket* locomotive of 1829 (Colour plate 1). This preceded its return to the Science Museum in London for display in its new *Making the Modern World* gallery. The study was supervised by Richard Gibbon, Head of Engineering at the National Railway Museum, and its findings were set down in a comprehensive and fully referenced report to the Museum, which has been published in full.[3] The manner in which the study was conducted, and its principal findings, form the present case study of learning through industrial archaeology.[4]

Background

Although *Rocket* is one of the world's best-known locomotives, rightly perceived as being the progenitor of main-line railway motive power, its interpretation has been limited to its success at the 1829 Rainhill Trials, and to its being the first locomotive fitted with a multitubular boiler. *Rocket*'s importance as an artefact is much wider, however, as it was:

- an important example of a prototype locomotive manufactured during the time of rapid design evolution and component development between 1828 and 1830
- designed and manufactured during the period of transition between the millwright-based manufacturing practice of the early locomotive builders and the factory-based practice that developed from the late 1820s
- the first example of a machine able to convey people at a sustained speed in excess of that which was possible by animal power
- the earliest surviving example of a locomotive which was maintained and modified by railway and contractor teams charged with keeping a fleet of main-line locomotives in service
- employed as a test-bed for dynamic and thermodynamic experiments, at a time of high expectation that further traction improvements, beyond reciprocating engines, were possible.

The research study sought to build on the work undertaken during the 1920s by the three respected locomotive historians, E A Forward, J G H Warren and C F Dendy Marshall.[5] Their work had formed the basis for the design of the replica built in 1929 for Henry Ford (on display in the Henry Ford Museum in Dearborn, Michigan), three later museum-displayed replicas of *Rocket*, and the fifth, operable, example, built in 1979 under the supervision of Michael G Satow, which is regularly steamed at the National Railway Museum.[6]

Although several components were removed in the years immediately after its withdrawal from service, the remains of *Rocket* represent a physical 'chronicle' of engineering design and maintenance practices between 1829 and 1840. To develop a more comprehensive understanding of the technological context in which *Rocket* was built and later modified, its design and manufacturing features, and its operating and maintenance history, the study was carried out through the combination of three disciplines:

- **Industrial archaeology**, being a comprehensive survey and systematic paper-and-photographic recording of the form, dimension and material of surviving components
- **Engineering**, being the determination of the reasoning behind the locomotive's design and the manufacturing method of each component
- **History**, being a comprehensive archival study to ascertain the events and decisions taken during the locomotive's career, and the context in which they occurred.

The survey was carried out in four phases, namely component removal, systematic recording, historical assessment and reassembly. From this survey, component and arrangement drawings were prepared using computer-aided design software. The drawings included all fittings and redundant holes and marks, as well as dimensions. The likely history of each component was sought using the drawings and the photographic record, in conjunction with the findings of the historical research.

Historical context

Rocket's importance as an artefact reaches far beyond its status as the well-known locomotive that won the Rainhill Trials, and the perception of it as the progenitor of the main-line railway locomotive. An understanding of *Rocket*'s specific place in locomotive development and the origins of main-line railway operation provided a background against which the findings of the survey were assessed and a guide to consideration of the artefact's future display and interpretation.

Rocket was manufactured by Robert Stephenson & Co. in Newcastle upon Tyne in 1829 during an intense period of locomotive development. This was necessary to advance its capabilities from those of the slow and relatively unreliable 'colliery' type used in the coalfields of the North East, to those of a machine capable of meeting the much greater speed, load-haul and reliability requirements of main-line operation. In the 33-month period between January 1828 and September 1830, locomotive technology advanced from the colliery type to the prototype *Planet*, the first class adopted for main-line operation.

The stimulus to this development programme was the strong advocacy for the use of locomotives by George Stephenson (1781–1848), Chief Engineer of the Liverpool & Manchester Railway.[7] The building of the railway required Stephenson's almost full-time attention, however, and thus his son, Robert Stephenson (1803–59), began a programme, at their Newcastle factory, to accelerate locomotive development towards the requisite main-line standards.

Robert Stephenson's programme, conducted in consultation, through correspondence, with his father, was a systematic appraisal of component and material improvement, rather than the incremental and empirical approach hitherto taken. This significant change to the method of technological progress saw improvements to the boiler, steam pipe, transmission and suspension. Improved materials were particularly required to fulfil the increasing dynamic and thermodynamic requirements of the developing locomotive. During the development programme, the Stephensons manufactured several experimental locomotives for customers in Britain, France and the United States, each of which incorporated innovations.

Rocket was an important example of this programme, designed to meet the weight, performance and other specifications determined for the Rainhill Trials.[8] As well as being the first locomotive to be fitted with a multitubular boiler and separate firebox, it also incorporated the most successful components already developed by the programme, namely the steel leaf spring and direct drive between piston and wheel crank using a crosshead, slide bars and connecting rod.

The *Planet* class, the prototype of which was delivered to Liverpool shortly after the opening of the line, incorporated significant improvements over the earlier locomotives, including *Rocket*, and became the first class of main-line locomotives used on several of the world's earliest main-line railways. The post-Rainhill improvements included:

- improved steam generation, by the adoption of a greater number of tubes of smaller diameter providing a larger heating surface, and the provision of a smokebox, improved blast pipe and firebox integrated within the boiler barrel
- increased thermal efficiency by the incorporation of a dome and internal steam pipe and the use of inside cylinders
- improved dynamics through the provision of horizontal inside cylinders, a substantial outside frame and the use of a leading carrying axle
- improved adhesion by the use of driving wheels at the rear of the locomotive, adjacent to the firebox.

Rocket was retrospectively fitted with some of these improvements when opportunity arose, but, after 1833, it was no longer economic to make further modifications. *Rocket* and its sister locomotive *Invicta*[9] are thus important artefacts that reflect the design and material achievements from this era of rapid technological progress.

Rocket is also important in representing one of the earliest achievements of mechanical design engineering. At the beginning of the development programme, Robert Stephenson recognised the need to introduce a design capability to provide a much-improved size and weight envelope within which components would be manufactured and fitted.[10] Innovations were incorporated within this envelope, whilst meeting a stipulated weight limitation and using different materials according to component specifications. This contrasts with earlier locomotives that had been developed and assembled in accordance with the long-established machinery and engine-fitting practices of millwrights and engine-wrights, and of other tradesmen working to their overall schemes. For these locomotives, schematic preproduction drawings only were produced, and neither general arrangement nor component drawings were prepared.[11]

Further improvements on later locomotives, including *Rocket*, were made possible by improved components and arrangements incorporated into more detailed drawings. By the summer of 1830, the

Planet-class locomotives had significantly better power-to-weight ratio within the strict axle-load limitations.

Operating speed on locomotive-hauled railways prior to the Rainhill Trials was typically 5 to 8 mph (8 to 13 km/h). *Rocket* incorporated significant dynamic improvements as well as the ability to generate more steam. It was 'made expressly for 12 miles an hour' when hauling a load of three times its own weight, and achieved this speed on its initial trial outing at Killingworth.[12] At the Rainhill Trials, *Rocket* exceeded the expectations for main-line locomotives when, with its assigned load, it achieved runs of between 14 and 24 mph (23 and 39 km/h).[13] At the conclusion of the trials it ran, without a load, at 35 mph (56 km/h),[14] thus trebling the previous maximum speed for a locomotive. For the first time, a speed had been achieved which exceeded that which could be achieved on horseback, which sent the symbolic message that the world was approaching an era in which it would no longer be dependent on horses for long-distance travel.

Rocket was the first locomotive to be adopted for main-line railway service, and its preservation therefore provides an excellent opportunity, through survey, to understand early main-line maintenance and repair practices, particularly for the boiler and wheels. The higher main-line operating speeds, for which the locomotives proved capable, subjected them to dynamic forces well beyond previous experience. This was compounded by material unreliability and the inadequacy of some initial fitting practices. The intensity of service on the railway was also much greater than had been anticipated, limiting the maintenance time for locomotives.[15]

The problems of maintaining an adequate locomotive fleet led the railway from 1832 to develop a much higher capability for maintenance in its locomotive running sheds, with correspondingly less dependence on outside firms. As experience grew, the sheds were better equipped, becoming the progenitors of the latter-day large railway workshops. The *Rocket* survey identified replacements, modifications and repair work of the railway's early maintenance teams, providing wider evidence relating to their developing role.

The majority of *Rocket*'s time with the Liverpool & Manchester Railway was spent on works trains and other secondary duties. It was involved in four serious accidents, the first being the well-known fatality to the Liverpool Member of Parliament, William Huskisson. Damage was sustained in accidents at Chat Moss in October 1830, Olive Mount cutting in January 1831 and on the Wigan Branch Railway in November 1832. The necessity to return to Liverpool for repairs on each occasion provided the opportunity to modify *Rocket* with the improved features.

Rocket was demonstrably better than its competitors at the Rainhill Trials, and the Stephensons' development programme for the reciprocating locomotive went on to produce significant improvements in both performance and efficiency with the *Planet* design. There was, however, an anticipation that 'further improvements' could be made, and for the more promising ideas locomotives were made available for testing purposes.[16] Following its withdrawal from regular services in 1833, *Rocket* was employed as a test vehicle for at least two of these schemes, including an unsuccessful rotary engine experiment, proposed by Lord Dundonald. As an artefact, the locomotive therefore takes on a further significance in providing an opportunity, through survey, to obtain a better understanding of these alternative technologies.

In 1836 *Rocket* was sold to the Earl of Carlisle, whose independent Naworth railway system linked his several collieries in Cumberland. It was retired from service by the colliery lessee, James Thompson, in about 1840, but was retained out of sentiment rather than scrapped. In 1862, Robert Stephenson & Co. prepared it for exhibition at the Patent Office Museum, latterly the Science Museum, at which site *Rocket* has been subsequently displayed.

Three contemporary drawings of *Rocket* were consulted during the survey. The first, retained in the Science Museum, depicts *Rocket* as it looked when sold by the Liverpool & Manchester Railway in 1836, by whom it was prepared in recognition of its historical association with the line. The second, privately-owned, drawing became known about as the result of the project research work. Watermarked 1839, it depicts the locomotive as it looked when withdrawn from service, and is almost identical to another drawing, retained in the National Railway Museum, but which does not have a watermark (Colour plate 2).

Survey methods and techniques

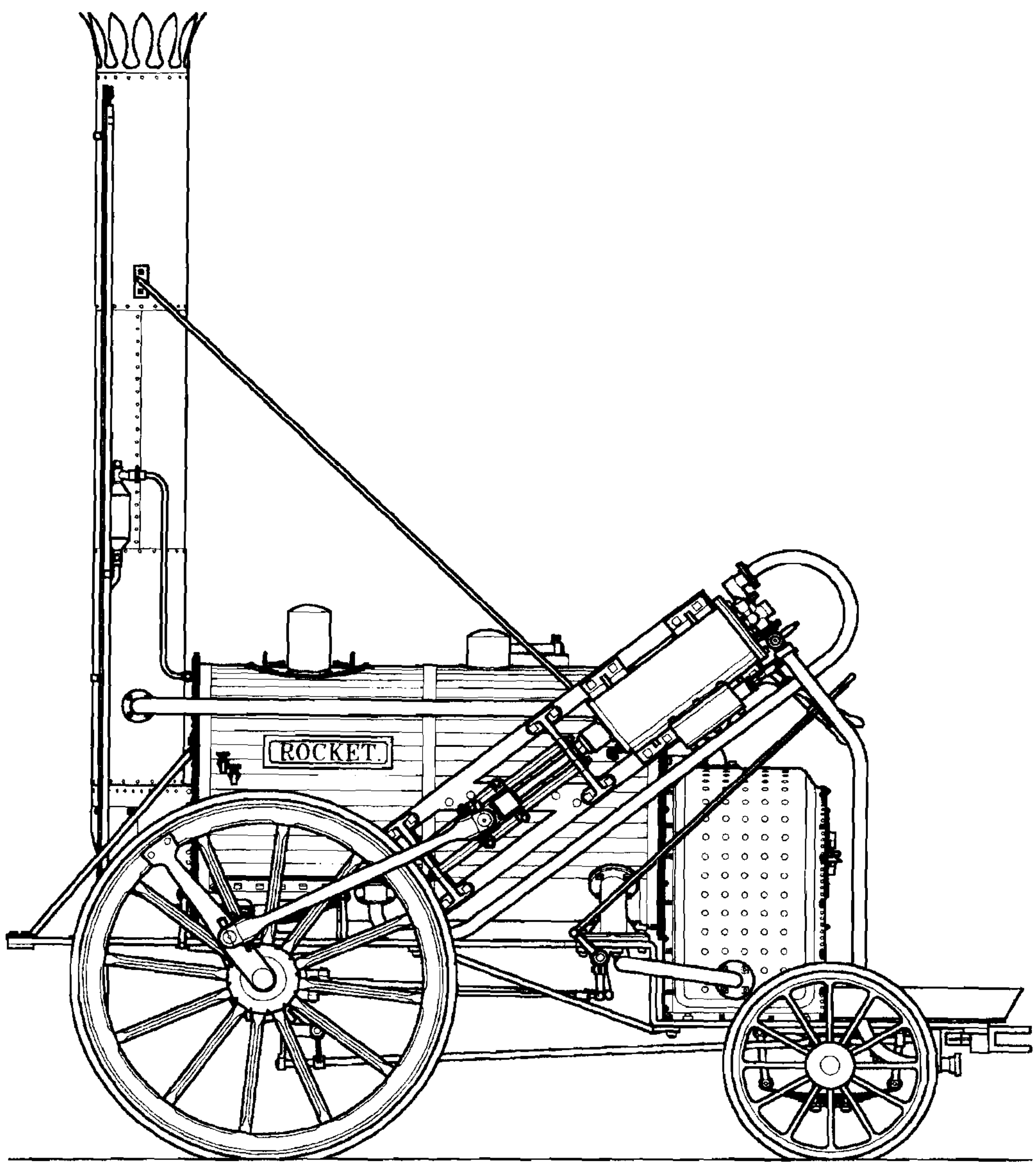
Following a review of the benefits of dismantling, selected components were carefully removed, with minimum risk to the artefact. Only those components that were to be of benefit to the survey were selected for removal. Photographs were taken of each assembly before dismantling. Easing oil was applied prior to removal of nuts and bolts, and brass shims were used within the jaws of spanners to avoid marking their heads. Components were carefully cleaned, labelled and weighed prior to survey (Colour plate 3).

A systematic programme of photographic recording and detailed examination was undertaken for each component, in order to ascertain:

- its material
- its dimensions
- the method of manufacture, machining and fitting
- the presence and dimensions of rivets, studs, bolts and nuts
- the presence and dimensions of redundant holes
- the presence and likely purpose of fitters' marks.

From this survey, drawings were prepared for each component, showing all fittings, redundant holes and marks, as well as dimensions, to aid assessment of component history. In conjunction with the research into the locomotive's career, the drawings and photographs provided an understanding of the likely history of each component, including an assessment of dynamic and thermodynamic characteristics. On completion of the report, all components were reassembled and restoration carried out to the limited surface areas that had been affected.

Figure 1 Rocket *in its original form as derived from the survey evidence. (John P Glithero)*



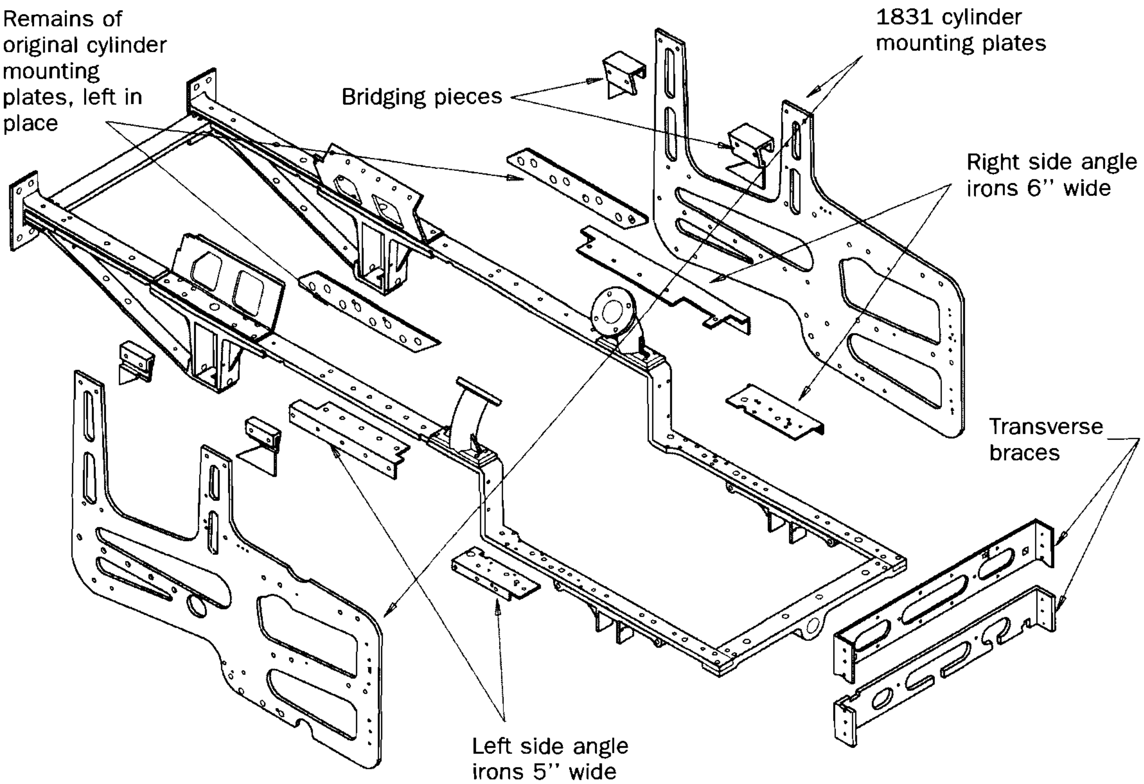


Figure 2 Example of a survey drawing: exploded view of structural components. (John P Glithero)

Main survey findings

The evidence from the survey now provides a clearer understanding of *Rocket*'s as-built form and of the design processes with which it was made. From this evidence, Figure 1 is now believed to represent its original appearance. Its arrangement was developed from the earlier prototype locomotives, notably the *Lancashire Witch*, which operated on the Bolton & Leigh Railway. The chosen four-wheel option limited its weight to 4½ tons.

The original main frame of rolled iron bar survives (Figure 2). The driving wheels were made of wood, but were fitted to a 3¼-in.-diameter axle, to minimise the weight. It is most likely that straps, to accommodate the crank bosses, had been fitted between the naves and the rims. Cast-iron horns, bronze bearings and steel springs were used, their original location being identified on the frames.

The original boiler barrel and tube plates have survived, and provide evidence of several missing fittings. A weighted safety valve had been fitted to the top of the rear plate, while a second, 'lock-up' safety valve was fitted into the door of the inspection hole in the leading plate.

The novel firebox, made necessary by the multitubular boiler, was formed from two copper plates into a 'saddle'-shaped crown and sides. To provide a 3-in. stayed water space, the outer plate was made in an 'ogee' form, while the inner plate remained flat. Although the saddle was removed during the 1840s, the evidence from the frame and back plate confirms that it was out of true both in plan and end views, other fittings being correspondingly asymmetrical.

The surviving regulator valve originally drew steam directly from the upper boiler space, resulting in 'priming', which was accentuated by *Rocket*'s speed and the gradients on the Liverpool & Manchester line. This necessitated a low water level in the boiler, confirmed by stopped-up sight-glass and gauge-cock fitting holes. The cylinders and driving motion were originally set at 38° to the horizontal, as confirmed by the surviving members of the original cylinder-mounting frames. The locomotive would thus have been unsteady in its first months of operation. It is most likely that slip-eccentric valve gear, fitted to the original driving axle, was similar to the surviving fittings on *Invicta*.

The progress made in locomotive technology in the year after the Rainhill Trials was rapid and far-reaching, and *Rocket* was fitted with some of these improvements when the opportunity arose. One such innovation, first fitted to *Invicta*, was a steam 'riser' inside a boiler-top dome, and steam pipe directing dry steam to the regulator that largely prevented priming. In October 1830, following its derailment near Chat Moss, *Rocket*'s inspection-hole door was replaced with a new fitting incorporating a dome, and a riser and steam pipe fitted internally. This allowed the water level to be raised by 3 in., as confirmed by a second set of sight-glass and gauge-cock fitting holes. The displaced second safety valve was refitted towards the rear of the boiler. The evidence thus discounts the long-held perception that *Rocket* had been fitted with a dome when first constructed. The original firebox back plate was replaced by the surviving wrought-iron water-jacket back plate, fitted within the rear of the saddle, and providing evidence of its form.

Rocket was then rostered for passenger duties, but in January 1831 it was badly derailed in Olive Mount cutting, Liverpool, and further repairs and modifications were undertaken. To reduce the locomotive's instability, the cylinders and motion were relocated to a near-horizontal position. The original cylinder-carrying frames were cut away, and large wrought-iron plates substituted (Figure 2). The plates, stiffened across the rear of the firebox back plate with transverse braces, made the routing of the valve gear more difficult. To overcome this, the cylinder and valve chests were exchanged side for side and inverted.

The leading end of the frame was badly bent in the accident and appears to have been straightened by cold hammering resulting in the breaking of the left side member. The frame was strengthened at the leading end, to which was fixed an oak buffer beam and draw eye. New wooden driving wheels were made, fitted to a 4-in.-diameter axle, which appear to be the surviving wheel set (Colour plate 4). The wheels have cast-iron naves keyed to the axles with rectangular steel keys. The wooden spokes and felloes are in line rather than the concave form of conventional road carriages. Wrought-iron rims were secured with bolts, and wrought-iron tyres shrunk onto the assembled wheels. The surviving slip-eccentric valve gear was probably fitted to the 4-in. axle at this time.

In November 1832, *Rocket* was involved in a collision with a coal train near Wigan. The repairs appear to have included the remaking of the right-side driving wheel, the spokes and felloes of which show differences from those of the left-side wheel. The opportunity was taken to replace the boiler tubes, rebore the cylinders and provide new pistons, fitted with brass rings and steel springs.

The October 1834 trial saw rotary engines fitted to *Rocket*'s driving axle. It is assumed that steam for the engines was drawn through the front tube plate, with steam pipes routed to the driving axle. There is a blank flange on the upper part of the front tube plate covering what was probably a steam-pipe opening, and which may well be the only surviving evidence of the trial.

Rocket was out of use for many months before being restored for sale by the Liverpool & Manchester Railway, and it would appear that the surviving smokebox was fitted at this time. The Naworth colliery workshops fitted supplementary buffers, beneath the main buffer beam, for use with the coal wagons. The leading end of the locomotive had, however, sustained a further collision, which left the main and supplementary frames buckled, and the buffer beam sloping (Colour plate 1).

Several prominent components were removed after withdrawal, and, in 1862, Robert Stephenson & Co. prepared *Rocket* for display at the Patent Office Museum by erroneously replicating several of the missing components. It remained on display in this condition for thirty years, but in 1892 the carrying wheel set was replaced. With greater curatorial involvement with the artefact in the twentieth century, the replicated components were removed, as were the supplementary buffers and braces. The last modification to be undertaken, in 1935, was the fitting of the surviving replica chimney.

Interpretation

It is clear that visitors find difficulty in understanding *Rocket*'s surviving components and the dynamic and thermodynamic principles that lay behind them. There is, firstly, a preconception arising from the visitor's expectation to see the locomotive in its 'as-built' condition, with livery being only a small part of this expectation. The position of the cylinders, the addition of the smokebox, and the lack of several prominent components all contribute to the interpretative problem. More importantly, one of the basic messages that visitors find difficult to understand, and which applies to many artefacts in technical museums, is that machinery has undergone modification and improvements during its working life, arising from operating experience and advancement in technology and material knowledge. This difficulty will increase as the proportion of visitors with memories of working steam locomotives diminishes.

From both the historical and interpretative standpoints, therefore, mechanical artefacts should be displayed in their end-of-service condition, incorporating the evidence of the improvements made during their working life. They should be accompanied by interpretative material to enable the visitor to understand the technological progression during the life of the artefact and the reasons for the improvements. This is particularly true of *Rocket*, whose modifications form an important part of its history. In the absence of an interpretative strategy, however, the locomotive now has a derived rather than planned appearance, which neither relates to its end-of-service configuration nor fulfils visitor requirements.

This recent survey of the locomotive and the resulting increase in knowledge about it therefore provide the opportunity for an improved interpretation for the Museum visitor. The contemporary drawings have provided new evidence towards a more comprehensive understanding of *Rocket*'s form at the end of its service. From them, it is now possible to consider a strategy for its future interpretation, by offering the opportunity to re-create those components that would enhance the visitor's understanding of the locomotive.

The debate concerning an improved interpretation needs to take account of both the importance of the surviving components as historic artefacts for the discerning visitor to see and understand, and the need to develop the locomotive's display for the benefit of the majority of visitors. There are, thus, four basic options for its display, with several variations according to circumstance:

1 Continue to display the locomotive in its current form, without alteration.

2 As 1, but with the replacement of the erroneous replica chimney and trailing wheels with correct versions based on the contemporary drawings.

3 Replicate some of the missing components to combine the advantages of showing both the remains and providing an improved interpretation.

4 Replicate all of the missing components, based on the contemporary drawings, and fit them to the locomotive to restore it fully to its end-of-service appearance.

Option 1 would not take advantage of the greater knowledge about the locomotive that is now available, while option 2 would at least correct the errors made during the locomotive's time in the Science

Museum. The extent to which it would be desirable to replicate missing components is itself conditioned by interpretative opportunities and the need to meet the needs of the discerning visitor.

It was therefore recommended that partial replication of the locomotive should be undertaken, based on both the contemporary drawings and the evidence obtained from the survey. The important principles of this strategy are:

- It should be fully reversible, thus ensuring that further changes could be made, should additional evidence become available.
- It should not in any way be damaging to the remains.
- The replica components should be made, as far as possible, from the same materials as the original ones.
- The components should be fitted to the remains using surviving holes and studs, with replicated bolts and nuts.
- The components should be stamped with the Museum name and date to clarify their origin for future generations.
- Full records of the changes should be kept.

There are a number of variations to partial replication, but to stimulate the debate about its extent, it was proposed that, in addition to replacing the chimney and trailing wheel set, one side of the locomotive should be fitted with replica components, leaving the other side in its present form. This would provide the visitor with the opportunity to view the locomotive, from either side, both in its end-of-service and preserved conditions.

With the assistance of textual, model and diagrammatic displays, *Rocket*'s progression from its 1829 to its 1840 configurations, based on the findings of the survey, could thus be fully explained to future generations of Museum visitors. The extraordinary international interest that the locomotive has generated over the years has led to the production of several working and non-working full-scale replicas. These have all related to *Rocket*'s 'as-built' form, and have been made out of the strong desire to interpret the technology of the locomotive at the Rainhill Trials. These have increased knowledge of the locomotive's original arrangement, component design and assembly, as well as its operating and maintenance characteristics, and have also served to accentuate the perception that the locomotive was the progenitor of main-line motive power.

Conclusion

Rocket's survival is remarkable both because of its public 'persona' as of one of the world's most historic industrial artefacts, and because it is an engineering 'time capsule'. Its components are a combination of the changing design, material and manufacturing characteristics of locomotive technology at the dawn of main-line railways. The authors' published report developed the study's findings, with sections on the condition of each component and the evidence regarding service wear and maintenance procedures. Such detail has provided a special insight into the locomotive's manufacture and operating life. The findings are now available not only to scholars of early railway technology, but also to museums of science and industry around the world. The principles that have been applied to the *Rocket* project may equally be applied to other industrial artefacts.

The knowledge gained from this project demonstrated the benefits of such a detailed survey, combined with intensive archival research. This has both enhanced understanding of the technology of the early main-line railway era and set aside some of the misperceptions of previous historical accounts. This greater understanding of the rapid development of the skills and knowledge of both engineers and artisans relates as much to material, manufacturing and component capabilities and limitations, as to the arrangement, assembly and maintenance of the whole machine. The evidence has further provided a better understanding of the decision-making processes towards the application of developing dynamic and thermodynamic knowledge.

It is a characteristic of all machinery that modifications are made during its working life, taking advantage of technological advances and improved materials, manufacturing and maintenance techniques. The findings of artefactual research projects thus provide opportunities for improved interpretation of these techniques and their evolution. Such interpretation may include partial replication of missing components to enhance the understanding of the whole artefact for both museum students and general visitors. Textual, model and diagrammatic displays should complement such restoration through sequential presentations of the artefact's progression, with explanations for the improvements and their benefits.

With artefacts being presented in their final form after a lifetime's work and incorporating all modifications, research projects may provide sufficient evidence to determine their original form. A beneficial form of interpretation for much-altered artefacts, such as *Rocket*, is therefore full replication, especially working examples. Such replication projects can, of themselves, enhance knowledge of arrangement, assembly, operating and maintenance characteristics of long-disused machinery. The challenge for museums is therefore to develop the most appropriate artefactual displays that allow visitors to interpret their historic machinery and the technological advances that they represent.

Notes and references

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8 Bailey, M R and Glithero, J P, note 3, pp171–3

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10 Bailey, M R, 'Robert Stephenson & Co. 1823–29', *Transactions of the Newcomen Society*, 50 (1979–80), pp123–7

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