

**A report for the Trustees of the Science Museum Group into the restoration of A3 Class Pacific  
*Flying Scotsman* and associated engineering project management.**

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## 1. Executive summary

Locomotive 4472 *Flying Scotsman* was purchased for the nation in April 2004 at a cost of £2.3m by the National Railway Museum (NRM)<sup>a</sup>, through a sealed-bid auction process. It ran intermittently until December 2005 at which point it was withdrawn from traffic to undergo a major overhaul. The original objective was for the repair to last 1 year and cost about £750k. This proved to be over-optimistic with the work still unfinished 6 years later and the cost likely to exceed £2.6m. The overhaul and renewal of *Flying Scotsman* has turned out to be one of the most extensive restoration projects ever undertaken in the heritage railways sector. This investigation was set up to discover why it is so late and so much over budget.

The reasons for the delays and cost escalation can be summarised as follows:

1. The condition of the locomotive when purchased was poor. In almost 50 years of post-BR ownership, it had a large number of owners, several of which failed financially. It had been heavily used and maintenance standards had been neglected.
2. The pre-purchase inspection was rushed and painted an overly positive picture.
3. NRM failed to undertake an adequate investigation of the condition of the locomotive, either when it first took ownership or at the start of the refurbishment. Consequently the original budget and timescale for the refurbishment were not based on engineering reality.
4. For much of the time, project management was ineffectual or non-existent. Since the project started, half a dozen different people have been in charge, few of whom had experience of managing a £2m engineering project. It has not been possible to find proper scope or planning documentation for the project.
5. NRM's supply chain was largely restricted to the heritage railways sector. This is a cottage industry that had difficulty in working within the formal contract management procedures expected of a publically-funded organisation. Several suppliers failed to meet their contractual targets but NRM's contract management system was ineffective in resolving the problems.
6. The NRM engineering organisation was inadequate for the scale of the work or for supporting the formal contract management structure. Staff losses and illnesses and delays in recruitment exacerbated the situation.
7. There were conflicts between the curatorial desire to retain as many original components and assemblies as possible and the need to produce a locomotive meeting the stringent demands of Network Rail for main line operation.
8. There were also conflicts between the desire of senior management for the locomotive to be seen at public events (the public having funded the purchase) and the need to pursue a structured engineering refurbishment programme.

These issues are discussed in more detail in the body of the report, which also recommends actions to reduce the likelihood of other projects suffering similar problems.

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<sup>a</sup> The National Railway Museum is part of the Science Museum Group (SMG) formerly known as the National Museum of Science and Industry (NMSI).

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## 2. Objective of report

Locomotive 4472 *Flying Scotsman* was purchased for the nation in 2004 at a cost of £2.3 million. It ran in preservation for a further year at which point it was withdrawn from traffic to undergo a major overhaul. The original objective was for the repair to last 1 year and cost £750k. This has proved to be an over optimistic outcome with the repairs still unfinished and with a new budget likely to be in the region of £2.6 million. Following the discovery of additional problems, completion is now anticipated in late 2013.

The objective of this inquiry<sup>1</sup> is “to conduct full research into the origins of the [restoration] project and its subsequent management from the engineering perspective. The report is not to focus on individuals but is to draw general lessons and conclusions, including recommendations. The following are areas to be covered:

- ◇ Engineering history of the locomotive pre-purchase.
- ◇ Steps taken to assess the engineering condition of the locomotive before purchase.
- ◇ Condition of the locomotive on purchase.
- ◇ Maintenance history of the locomotive for the first 12-18 months of ownership and operation, and nature of problems discovered at that time.
- ◇ Viability of the initial restoration plan.
- ◇ The extent to which NRM Engineering capability and organisation was capable of conducting the restoration.
- ◇ Project management and project ‘drift’.
- ◇ Engineering support and capacity required both to maintain and operate the locomotive once complete.
- ◇ Recommend future NRM engineering requirements and core competences both to restore/maintain operational locomotives and to maintain the static fleet in the National Collection.

Access was provided to relevant documents and interviews were held with NRM staff associated with the project and other parties involved (listed in the Appendix).

## 3. Brief history of *Flying Scotsman* prior to NRM ownership

The locomotive was originally built by LNER as a Class A1 in 1923. On 30 November 1934, it was the first steam locomotive to be officially recorded at 100 mph.

*Flying Scotsman* was rebuilt in 1946-7 as a Class A3, with its boiler pressure increased from 180 psi to 220 psi and carried out a variety of roles under BR ownership until it was withdrawn from service in 1963 when it was sold for preservation and restored at Darlington Works as closely as possible to its LNER condition.

Following another overhaul in 1968-9 by the Hunslet Engine Company, *Flying Scotsman* went on a tour to the USA, for which it was fitted with cowcatcher, buckeye couplings, and other American equipment. This ended in bankruptcy and a change of ownership. The locomotive was returned to Britain in 1973 and was overhauled in Derby Works. It was subsequently based in Carnforth Steamtown, where it was used for rail tours. In 1978, during another overhaul, it was fitted with a Class A4 boiler, which allowed the working pressure to be increased to 250 psi during a 1999 overhaul.

In 1988 the locomotive was transported to Australia for the bicentenary celebrations and ran more than 28,000 miles in steam. Returned to the UK, by 1995 it was in pieces at Southall Railway Centre in West London with an uncertain future.

It has not been possible to find a complete modification record of the locomotive but, at various times when it was in private ownership, the following modifications are reported to have been made<sup>b</sup>:

- ◇ Removal of the vacuum brake system from the locomotive and tender and replacing it with an air brake system similar to Class 37 diesel locomotives.
- ◇ Fitting a steam powered air compressor and auto air brake control equipment to enable the locomotive to work with air braked vehicles.
- ◇ Replacing the steam-operated sanders with air sanding.
- ◇ Replacing the cable operated cylinder cocks with steam operated cocks.
- ◇ Replacement of the middle cylinder with a recovered item.
- ◇ All Cartazzi <sup>c</sup> and bogie tyres renewed.
- ◇ Driving wheel tyres renewed in 1988 and tender tyres in 1992.
- ◇ Superheater header modified with a larger 7" diameter outlet flange.
- ◇ Double chimney and Kylchap blast pipe assembly fitted.
- ◇ Locomotive drag box and a length of main frame renewed.
- ◇ All three crossheads renewed.
- ◇ New copper firebox backplate fitted.
- ◇ All boiler tubes renewed.
- ◇ New superheater elements fitted.
- ◇ Foundation ring removed, repaired and re-fitted.
- ◇ Steel outer firebox side and throat plates, lower part renewed.
- ◇ (Mandatory) spark arresting equipment fitted.
- ◇ TPWS and other safety systems installed.

The last private owner had *Flying Scotsman* restored over three years to running condition at a cost of £1 million. However, following yet another bankruptcy, the locomotive was put up for sale and bought by the NRM.

This history is important for understanding the engineering challenges faced by the NRM; more details can be found on the internet<sup>2</sup> and in the specialist press.<sup>3</sup> Over its life, *Flying Scotsman* has been extensively modified; in the 49 years since it was withdrawn from service on BR, it had several owners; it has been modified to meet the requirements of mainline running in the USA and Australia, as well as the UK; its power has been increased by increases in boiler pressure, changes to the boiler and valvegear, and it has been “restored” several times to correspond (at least visually) to the condition it was in during the hey-day of steam.

Since it passed into private hands, the locomotive has been subject to major overhauls in 1965, 1968, 1973, 1978, 1989 and 1999 and any number of minor interventions. However, unlike the overhaul of a modern locomotive, which takes place against a set of detailed component and

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<sup>b</sup> List taken from AEAT report (see references)

<sup>c</sup> A Cartazzi is the two-wheel floating axle under the cab. F. I. Cartazzi was a senior engineer of the Great Northern Railway who, in 1866, became locomotive superintendent of the Great Indian Peninsula Railway. He invented the Cartazzi radial axlebox for trailing carrying wheels. This supported the axleboxes on inclined planes, so that the weight of the locomotive provided a centring force for the axle assembly.

material specifications, process schedules and toleranced drawings, these have been more *ad hoc* with the fitters using judgement about acceptable processes, tolerances and materials. Looking back up to 40 years, it has not been possible to determine whether the brief to those undertaking the work was to seek out and rectify any fundamental problems with the locomotive or whether it was to do the bare minimum to get it back in service. Bearing in mind the shaky business plans of some of the previous owners, the latter seems likely for at least some of the maintenance activity.

#### 4. Timeline for NRM refurbishment

The specialist press has taken a keen interest in the refurbishment of the *Flying Scotsman* and, in September 2012, published a detailed history of the project.<sup>4</sup> The key dates, as they relate to the objectives of this report, are reproduced below:

- Feb-04 Debt agency GVA Grimley, acting for Flying Scotsman plc, announces a 'sealed bids' auction. The deadline for bids is 2 April. NRM declares it will bid for Flying Scotsman.
- Apr-04 NRM is declared the winning bidder for *Flying Scotsman*, to include spare boiler, cylinders and Mk 1 support coach.
- May-04 *Flying Scotsman* suffers boiler tube failure.
- Jun-04 NRM puts out tenders for the contract replacement of 121 small tubes, so *Flying Scotsman* can run the three-days-a-week 'Scarborough Spa Express' (SSE), starting on 20 July.
- Jul-04 Three days into its operation of 'SSE' trains, *Flying Scotsman* fails with a damaged white-metal crosshead bearing. Five days later, locomotive fails again, with defective oil pump pipework.
- Aug-04 Concern over 'old' repairs to a serious crack in the right-hand cylinder.'
- Sep-04 *Flying Scotsman* is taken into the NRM workshop for a 'heavy intermediate repair' that ultimately takes nine months. It includes stitch welding of the cracked cylinder, crown stays renewal, complete replacement of large sections of inner firebox, and renewal of air brake fittings.
- Feb-05 Corrosion in the firebox reported, which will need specialist copper welding.
- May-05 Locomotive returns to traffic following its nine-month overhaul, but leaking crown stays means it completes only two of the three days of operation.
- Jun-05 Spare A3 boiler (built October 1944, carried 1965-1978) is sent to Riley & Son Ltd at Bury 'to be completely rebuilt, ahead of the A3's upcoming 'heavy general'.
- Oct-05 NRM statement that boiler washout plugholes had been fitted with domestic gas plugs. The 'Gresley clang' in the motion, is said to be 'due to some lack of alignment somewhere in the chassis or wheels - but this can only be fixed during the next major overhaul.
- Dec-05 NRM announces the A3's heavy overhaul will start in the Museum's own workshops on 3 January 2006 and says: "We plan to complete the work in August 2007". The press reports that corrosion to inner and outer fireboxes of *Flying Scotsman's* 'spare' A3 boiler (built 1944), being overhauled at Riley & Son Ltd, is so extensive that a new firebox will have to be built.

- Jan-06 NRM states that AEA Technology, the Museum's Vehicle Acceptance Body, 'guillotined' the A3's boiler certificate, because of the poor condition of the firebox. It had been certificated until March 2006.
- Feb-06 No. 4472's A4 type boiler is lifted from the frames at York.
- Dec-06 No. 4472's cylinders are re-bored, and it is announced that a new copper firebox will be built.
- Jul-07 A month before the original completion date given for the *Flying Scotsman* the NRM admits the overhaul 'could take another 18 months'. In a statement, the Museum says the delay is due in part to the need to obtain 'a special type of copper' for No. 4472's new firebox, now commissioned to contract boilermaker Roger Pridham.
- Feb-09 The A3-type boiler, with its new, Pridham-built firebox temporarily bolted in place, is trial-fitted at Riley & Son, Bury.
- Apr-09 NRM agrees to refit *Flying Scotsman* with vacuum braking, so that it can run with the Mk 1 passenger stock operated by most preserved lines.
- Jun-09 Following delivery of the A3 boiler from Pridham's, Tavistock, to Riley & Son, faulty welding is discovered in the new inner firebox. NRM orders independent NDT (non-destructive testing) of the boiler, by engineering consultants Frazer-Nash. The firebox is returned to Tavistock.
- The badly-cracked RH cylinder is replaced with the 'spare' previously fitted to No. 60041 *Salmon Trout*.
- Jul-10 The frames are sent to Riley & Son at Bury for what is described as 'the start of the next phase of the overhaul' - the complete replacement of the air brake system. It will then return to York for the rest of the framework to be completed, before returning to Bury again for final fitting and running-in. At Bury, the new smokebox tubeplate is machined.
- Jan-11 *Flying Scotsman* is re-wheeled for the second time, after the driving wheels are returned from Tyseley where defects are rectified by re-turning.
- Feb-11 The heavily rebuilt A3-type boiler is steam tested (out of the frames) at Bury to 230 psi (safety valves lift at 220 psi).
- Mar-11 The boiler is returned to the frames.
- Jun-11 Within days of the locomotive's return to Bury, cracks are discovered in the frame hornblocks. Arrangements are made to strip the running gear again and lift the frames from the wheels to conduct ultra-sonic frame testing.
- Aug-11 While remedial work on the cracked hornguides is going on, Frazer-Nash test for 'possible further cracks in the locomotive's frame stretchers'. NRM says that earlier in the overhaul, *Flying Scotsman*'s frames were found to be 'out of true', and that one of its driving wheels was 'bent'.
- Sep-11 Ultrasonic testing of No. 4472's frame stretchers confirms the 'worst case scenario'. All of the locomotive's frame stretchers (the horizontal steel braces which tie the two side plates together) are cracked; the main stretcher is deemed 'beyond repair'. The centre-cylinder motion bracket also has cracks, and is condemned. The A3 is dismantled again, and the boiler lifted out of the frames once more by Riley & Son at Bury.

- Dec-11 NRM announces that, during the recent stripdown, the frames were found to be wrongly aligned.
- Mar-12 It emerges that the frame's horn ties are scrap, and need to be remade.

## 5. Assessment of the condition of the locomotive before purchase

As part of the purchasing process, and prior to submitting the sealed-bid, the Museum commissioned AEA Technology to carry out a mechanical examination of the locomotive's condition. AEA were at that time the Vehicle Acceptance Body (VAB) responsible for the annual certification of the locomotive in order to enable it to operate over Network Rail lines. The inspection was carried out at Southall by three engineers who had considerable experience in the subject and who had previously been involved with the locomotive. Subsequently, a valuation report was commissioned from Swindon Railway Workshop Ltd.<sup>5</sup>

### 5.1. The AEA Technology pre-purchase report

The AEAT report<sup>6</sup> was remarkably positive. The key statements were:

*“The following mechanical areas of the locomotive were visually assessed and judged to be in a satisfactory condition for service on RCI [Network Rail Controlled Infrastructure]:*

- ◇ Frames
- ◇ Bogie
- ◇ Cartazzi
- ◇ Dragboxes - engine and tender
- ◇ Buffers
- ◇ Drawgear and couplings
- ◇ Valve gear and reverser
- ◇ Wheels, axles, axleboxes and horns (as far as could be seen)
- ◇ Cylinders
- ◇ Piston rods, crossheads (currently being re-metalled)
- ◇ Connecting and coupling rods
- ◇ Air pump and brake system
- ◇ Suspension springs and spring gear
- ◇ Tender frames
- ◇ Tender water tank
- ◇ Tender coal bunker
- ◇ Tender wheels, axles, horns and axleboxes
- ◇ Tank top
- ◇ Hand rails
- ◇ Safety Labelling
- ◇ AWS and TPWS systems
- ◇ Electrical conduits and equipment
- ◇ Battery box

The report continued:

*“It was not possible to check the water spaces adequately since the locomotive was being prepared for a test run. Only the front and rear upper wash out doors were removed. Observations of the available water spaces indicated that no untoward corrosion or scaling was evident and the water spaces were in a clean condition. The wash out door abutments seen appeared to be in an acceptable condition. Water treatment is not used.*



*The smokebox and steam pipes were hammer tested and rung out satisfactorily. The Kylchap blast pipe apparatus was clean with no evidence of char cutting. New tube end cinder screens had been fitted and the observed blast pipe screen was in good condition. Some leakage at the superheater wet header access plate had taken place and it had been fillet welded to obviate leakage. This was understood to be a temporary repair until the header could be removed when re-tubing was due. This will require future attention. One hot header door had been removed and the element ends seen to be in good condition. The smokebox door and ring appeared to be in acceptable condition.*

*The back head fittings exhibited signs of leakage and traces of scale deposit were in ready evidence on the combined boiler feed clacks and steam valves, the regulator box and various steam valves. The boiler pressure gauge exhibited a zero error of 15 psi. The fire door flap showed evidence of overheating and the baffle plate was wasted and was considered unserviceable. The firehole shovel plate appeared sound and all the firehole rivets tight.*

*In the firebox a sample of side stays were hammer tested and two adjacent stays found broken in the L/H front breakage zone. It was confirmed that this was a known defect that had been under observation for some two years and no other damage was evident in this area. The fire tube ends were beaded satisfactorily, however, the Owner's Representative was having all the firebox superheater flue ends fitted with stainless steel protective end cap ferrules. This was to prevent wastage at the beaded end/tube plate as problems had been continually experienced at this interface. The tube and back plate laps were in good condition and had been fillet welded to the wrapper to prevent leakage. There was no apparent leakage at the new monel metal rivets in the back plate but it was observed that the heads were either undercut or improperly closed during assembly (dolly too large).*

*Maintenance action was being carried out to the rear six to eight rows of roof stays. New stay nuts were being fitted. The previously fitted nuts exhibited signs of overheating and the stay ends were notably wasted or burned.*

*Due to an equipment failure, it was not possible to ascertain a sample of the firebox roof or tube plate thickness. There were, however, no visible signs of distress such as corrugations or bulging and the firebox condition appeared generally sound.*

*Whilst it was not possible to complete a thorough examination of the locomotive, or to witness it in steam, the condition of the locomotive has been monitored regularly as part of the VAB audit process. Taking this into consideration, it is considered that the general mechanical condition is satisfactory for continued operation, subject to effective maintenance, until the next General Overhaul in 2006. The scope of mechanical overhaul is not anticipated to be extensive but will involve strip down of the motion and axleboxes to gauge wear and remedial action. The cylinders all require re-lining and boring to nominal diameter.*

*With regard to the boiler and steam supply pipework, the observed condition appeared generally satisfactory. The two broken stays represent the maximum permissible breakage in this area of the firebox and the soundness of this locality must be kept under close observation until the stays can be replaced. There is evidence which may suggest overfiring or forcing of the boiler at the rear end of the firebox. This is manifested by the extent of burned roof stay ends, wasted nuts, burned out deflector plate, overheated door flap and build-up of oxide under the roof stay nuts. It is possible that the problems with the superheater tube-end headings and fire tubes has been exacerbated by over firing. It is also clear that the locomotive has been continually used to haul large loads often exceeding 600 tons. The repairs being undertaken at present should permit the locomotive to continue*

*main line operation up to the end of its current 7-yearly overhaul period. Due to the condition of the firebox as observed, it is unlikely that an extension to the 7-yearly period would be permitted, and a thorough boiler overhaul would be required."*

The official AEAT report had a different tone to the comments of one of the engineers, who had this to say about his experiences carrying out the inspection:

*"The inspection was requested by the NRM and took place only a matter of days before the purchase was committed ... very much at "the eleventh hour" ... a report was required the next day by the NRM. My colleagues asked me to carry out an inspection of the boiler in the afternoon. I started at the smokebox and was aghast to find that the Robinson superheater header doors had been seal welded. From memory, other inspection doors had also been seal welded. I detected two broken stays (which were known about previously). Fitters from [a contractor] were working in the firebox, attempting to reinstate the threads of the crown stays towards the fire door end. These were in very poor condition and the remedies being employed were not in my opinion satisfactory for continued operation. There were signs of overheating. For example, Admiralty pattern ferrules had been set (poorly) into some of the flue tube ends, some pink patches in the crown were observed after wire brushing and there was a deposit of sulphurous material all over the firebox. The tip of the fire arch appeared to be positioned too near to the door plate, most likely resulting in the fire stream being deflected further to the rear of the firebox crown sheet. The flap in the fire door was badly deflected into the cab indicating very high local temperatures. I did not see the deflector (it may have been burned away). The general condition of the boiler fittings was poor [and] the boiler pressure gauge registered 40 psi [when it should have read zero]. I was unable to gain a view of the water side of the boiler as the access doors and washout plugs were in place and no one was available to remove them. I did not think the boiler was fit to run without in-depth inspection and very likely a good deal of (good quality) repair work.*

*The "Condition Assessment" was undertaken in a hurry in less than a full working day, with little resource, assistance and in less than adequate conditions. At best it could only identify the visibly obvious defects. It would have taken a complete strip down, inspection and NDT testing to identify further inadequacies."*

The AEAT report included a number of photographs, including *Figure 1: Roof stay nuts*, which illustrates the point made in the interview and does not seem to back-up the rather rosier picture painted by the written report.



*Figure 1: Roof stay nuts (Photo: AEAT)*

While there is no suggestion that AEAT intentionally distorted their findings to give a positive impression, it is worth bearing in mind that they had been the VAB (Vehicle Acceptance Body) for *Flying Scotsman* for 14 years, during which time they had signed-off the locomotive as fit to operate on the main line. Suddenly to identify a large number of long-standing faults could have raised questions on their work over the previous decade. More probably, they suffered from a similar problem to that identified by Charles Haddon-Cave in the Nimrod review<sup>7</sup>:

*“The Nimrod Safety Case process was fatally undermined by a general malaise: a widespread assumption by those involved that the Nimrod was ‘safe anyway’ (because it had successfully flown for 30 years) and the task of drawing up the Safety Case became essentially a paperwork and ‘tick box’ exercise.”*

Having lived with the locomotive for more than a decade and certified it as fit to run throughout that period, AEAT would have had a natural tendency to assume everything was satisfactory unless demonstrably otherwise. If the museum was seeking a full and frank report on the locomotive condition, the previous owner’s VAB may not have been the best choice of inspector.

The duties of a VAB are specifically to ensure that a vehicle meets the regulatory requirements for operation on the Network Rail infrastructure. The only real detail in the report is about wheel flange thickness. The report also includes photographs of the air brake compressor, locomotive air brake, tender air brake cylinders, TPWS antenna selection switch and the TPWS antenna mounting arrangements. While these may be critical to obtaining necessary permissions to operate on Network Rail, they are not the first priority of a potential purchaser attempting to assess the condition of the asset they may be purchasing.

When interviewed about the purchase decision, the former head of the NRM said:

*“The owners offered the engine for sale by public tender and, whilst NMSI [now called SMG] might have taken an ‘easy come easy go’ approach to its bidding, content to miss out on the acquisition if its bid proved to be insufficient, the public expectation, from Ministers downward, was that the NRM would acquire the locomotive. The National Heritage Memorial Fund had indicated that it would be a major funder and 3000+ individuals had contributed to the fund. Put crudely, we were in the game to win it and the public and our stakeholders expected us to win.”*

*“We had no false expectations of the seller or the locomotive and I am quite clear that, although we undertook inspections and took advice, we would in practice be buying the locomotive ‘as seen’ and with no hope of reparation in the event that the locomotive turned out to be in worse condition than asserted by the seller and the seller’s agents.*

*Although I am clear that we went about the acquisition in a professional way, the job was to ‘save’ the engine for the nation – to get it out of the hands of its owners and to deal with the consequences afterwards. We had no illusions as to the condition of the engine and we weren’t disappointed in this assumption!”*

## **5.2. The valuation report**

In addition to the AEAT inspection, the museum obtained a professional valuation of the locomotive <sup>(referenced earlier)</sup>. Their report opens by defining their methodology:

*“For the purposes of this valuation we have been provided by our client with a draft copy of the offer for sale and a draft copy of a condition assessment by AEA Technology (AEAT).*

*From previous valuations of the locomotive and from our relationship with Venice Simplon-Orient-Express (VSOE), who are the principal hirer of the locomotive for their British Pullman and Northern Belle excursions we are in possession of other relevant information.*

*In the course of this assignment we have not met or discussed with anyone associated with the ownership of the assets, although in the course of inspecting the locomotive on 26 February information was obtained from a volunteer working on its maintenance.*

*We have previously (in 1990) carried out a valuation of the locomotive for its then owner, the Hon (now Sir) William McAlpine. We have previously carried out a valuation (in 1999) of Flying Scotsman Railways, at their request, which included the assets in question, amongst others. Although a portion of our fee for this work remains unpaid, we do not consider that this affects our objectivity or the validity of our conclusion.*

*During the course of the previous valuation we carried out a detailed cold examination of Flying Scotsman on 1 December 1999, and have subsequently observed the locomotive in operation on several occasions. Four years ago the locomotive was found to be in excellent condition. Since then the locomotive has successfully done a great deal of hard work, evidenced by the inspection on 25 February, 2004 by AEAT."*

In their conclusions, as well as comments on the financial value of the locomotive, which does not concern this report, the valuers said:

*"Unlike many other trophies, Flying Scotsman has been restored and in fact significantly upgraded, so that it can legitimately claim to be the most useful and viable main-line steam locomotive operating in Britain. Its recent performance more than justifies its reputation, despite the financial failure of the company owning it."*

*"Since the [1999] overhaul Flying Scotsman has operated for five of the seven years of its main line boiler ticket, so the value of the overhaul has been reduced. Nevertheless the next overhaul should be considerably less expensive, as the work done in the late 90's was so comprehensive. The engine has exceeded expectations, and regularly pulls the most glamorous trains in the country."*

The impression gained from the interviews with NRM management was that the museum had committed to its stakeholders – trustees, politicians, funding bodies and 3000+ private donors – that it would buy *Flying Scotsman* "for the nation", irrespective of its condition. There were press reports that it could be bought by overseas bidders<sup>8</sup> which added to the pressure. In a sealed-bid auction, there was no opportunity to use a condition report to negotiate on price and, to at least some extent, the report was commissioned because it was expected by funding and audit bodies, not because it would influence the decision to bid or the bid price. The decision to put in a winning bid had been made.

While the value of many engineering assets can be determined by cost-benefit analysis or comparisons with recent prices for similar products, it was recognised by the NRM management that the price of *Flying Scotsman* would be determined by factors similar to those for a famous work of art. In the end, the bid price of £2.3m was only 15% higher than the next highest bid so, by whatever process it had been decided, the NRM bid had been reasonable and the objective to buy the locomotive had been achieved.

## 6. Condition of the locomotive on purchase

At the time the auction, there had been strong rumours that the locomotive was in a considerably worse state than described by its owners. These were recognised by NRM staff, one of whom subsequently commented:

*“Those behind Flying Scotsman were very fond of portraying the locomotive as being in ‘better than new’ condition but it was common knowledge in the rail heritage community that this bore no relation to reality. My recollection is that Flying Scotsman had operated only a small percentage of its booked work in the year before sale because of reliability problems. This itself was indicative of problems. When the locomotive was offered for sale it was not in working order. On our first inspection, the rear drivers had been removed to deal with bearing problems. The visiting NRM team was most unimpressed with the quality of work being done on the bearings. Other examples of poor workmanship (of which I cannot remember the detail) were evident on inspection.”*

An internal report in October 2004 by the NRM Curator of Rail Vehicles discussed some of the issues that had been discovered since purchase.<sup>9</sup> The AEAT report had listed 18 mechanical areas that had been visually assessed and judged to be in satisfactory condition for continued service:

*“Subsequent experience with the engine has proved this not to have been the case in at least seven of these areas, although it remains questionable how much of this could have been revealed by an inspection which, through the requirements of grant submission timings, was undertaken with extreme haste.”*

The report continues:

*“On inspection at York it appeared that boiler washouts had been at best cursory and inadequate, the ensuing build-up of sludge from south eastern water masking a variety of serious problems. Despite this, problems enough were suggested, and this area of the report expressed the greatest level of concern over the management and operation of the locomotive; it was clear that stay nuts exhibited signs of overheating, as was suggested by the fitting of stainless steel ferrules in an attempt to reduce the evident wastage at the tube ends.”*

*“The [AEAT] report made it very clear that the writers considered that the engine as a whole, and the boiler in particular, was being used in excess of its design parameters and being forced, by performance-led requirements, to the point where damage was taking place well in excess of fair wear and tear.”*

*In retrospect it is the case that the locomotive has proven to be surprisingly reliable mechanically, considering and despite some truly appalling discoveries, such as valve condition (not, in fairness, something that this inspection could have revealed).”*

*“The two principal causes of concern during the 2004 operating period have been boiler and firebox issues; the other area is the most difficult to quantify and is the huge number of imperfections, ranging from the merely irritating to the frankly dangerous in countless fittings, brackets, pipework and connections etc. It is these that have caused the bulk of failures and unavailability for service. Such a brief survey could not perhaps be expected to catalogue such faults exhaustively, but should perhaps have made more mention of them as an indicator of the standards being applied, not only recently, but apparently for some time past.”*

Most of the comments in this report relate to the boiler and its associated systems, which was seen as the critical component in the locomotive – possibly because of the catastrophic results

of failure in this area and the consequent need to obtain specific certification. However, other problems came to light, as discussed in the following chapter.

## 7. Maintenance and operation of the locomotive in the first 12 months

Following purchase it was decided that the locomotive would be taken to York for working charter trains operating out of York. Embarrassingly it failed at Doncaster whilst *en route* to York with severely leaking boiler tubes and had to be towed in to the waiting reception committee at Railfest 2004. Following considerable remedial work it was put into service on charter trains such as the Scarborough Spa Express (SSE), which count as “light duties” compared with mainline operation. As mentioned above, the Curator of Rail Vehicles produced a report which documented operational experience of the locomotive between May 2004 and early October 2004. During this period numerous defects came to light, and the workshop staff were fully occupied in keeping the locomotive in service. It was becoming ever more apparent that the locomotive was truly worn out, and the stark contrast between the glowing commentary in the valuation report and the reality of the locomotive's condition could not have been more apparent. The curator's report records the following repairs were required in order to maintain the locomotive in traffic:

- ◇ The replacement of 121 boiler tubes, with consequent rectification work being required to the superheater elements which had to be removed to facilitate the tube replacement;
- ◇ Repairs to defective studs etc. on the superheater header;
- ◇ Caulking of firebox stays;
- ◇ The de-scaling of the firebox foundation ring and building up wasted areas by welding;
- ◇ Overhaul of the smokebox door locking mechanism;
- ◇ Extensive repairs to the firebox ashpan;
- ◇ Repairs to boiler mountings and pipework in the cab considered to be dangerous;
- ◇ The overdue Inspection of air brake reservoirs and re-certification;
- ◇ Replacement of 2 tender springs;
- ◇ Re-metalling one crosshead,<sup>d</sup> which resulted in having to remove the bogie, and led to the discovery that the piston rods were incorrectly fitted to the crossheads and required extensive repairs in order to make them fit properly;
- ◇ Removal of the 'belly' access door in the bottom of the boiler barrel in order to remove a build-up of some 6 inches of sludge. This would normally be easily undertaken as the door is provided for this purpose but in this instance the door had been welded shut, presumably because the previous maintainers were incapable of making it seal correctly;
- ◇ A flat spot on one of the tender wheel tyres;
- ◇ Making the previously inoperable tender handbrake work;
- ◇ Repairs to the air pump;
- ◇ Replacement of the vital axlebox oil pads which were long overdue for replacement.

The fundamental problems of chassis cracks and misalignment and distorted wheelsets had not been identified during this period; this may have been because NRM management were sensitive to the wishes of the donors who had contributed to the purchase of the locomotive and wanted to see it running in steam, not as a static museum exhibit. Thus, during this period, the pressure was to keep the locomotive operating and fix problems as they arose.

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<sup>d</sup> A crosshead is the mechanism between a piston rod and its crank that eliminates lateral or vertical forces on the piston rod.



In September 2004, the locomotive was taken into the NRM workshops for a “heavy intermediate repair”, where it remained until May 2005. The intermediate repair was intended to keep *Flying Scotsman* operational until the heavy general repair.<sup>e</sup> Unfortunately the intermediate repair appears not to have been successful, as reliability had not improved, and it was decided to start an 18-month heavy general repair, to include full restoration of the locomotive, in January 2006.

## 8. Viability of the initial restoration plan

It is not clear that there was ever a plausible restoration plan. Following the failure of the “heavy intermediate repair” to reduce the rate of failures, there was a list of known problems but there is no evidence of a survey adequate to detect other potential problem areas. Work started to rectify the known problems, particularly around the boiler, and the project stumbled into other problem areas over the following 5 years.

### 8.1. Refurbishing the A3 boiler

The locomotive was purchased with a spare boiler. The boiler fitted to the locomotive was of the type originally fitted to the later A4 class whilst the spare boiler was the boiler which had been fitted to the locomotive at the time of purchase from British Railways in 1963. The A4 boiler had prudently been purchased as a spare by the then owner during the 1960s and this had subsequently been judged to be in better condition at a periodic overhaul and consequently fitted to the locomotive in place of the original which was retained as a spare. Unfortunately it had been stored in the open and little conservation work was carried out to prevent further deterioration and corrosion. The A3 boiler (LNER type 94A) and the A4 boiler (LNER type 107) have identical outer dimensions but the A4 type has a larger firebox combustion space, a larger superheater and can work at the higher pressure of 250 psi compared with the A3 boiler pressure of 220 psi. From 1954 a number of new boilers were made for the A4 locomotives and the displaced boilers were used on A3 locomotives in order to replace life-expired A3 boilers. These boilers had their working pressure reduced to the 220 psi of the A3 class as those locomotives were fitted with larger bore cylinders.

At the time of the last overhaul in private ownership, it had been decided to change the boiler pressure to 250 psi, which with the larger A3 cylinders, resulted in the locomotive having a greater power output than either its original form as an A3, or indeed the nominally more powerful A4 class locomotives. Unfortunately this led to excessive demands on the locomotive which was deleterious to its long term condition. It was against this background that the NRM engineering team concluded that the A4 boiler had deteriorated to the extent that it was in a worse condition than the previously discarded A3 boiler. There was also a desire to return the locomotive to original condition, and so it was decided that the original A3 boiler would be the one to overhaul, and following commencement of the overhaul, the A4 boiler was surplus to requirements and sold to the owner of an A4 locomotive as a spare.

An invitation to tender (ITT) for the repair of the boiler was issued, and the firm of Riley and Sons was subsequently selected as the successful bidder. The ITT included a specification for the works, prepared by museum staff, which was based on reports of the boiler's condition supplied

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<sup>e</sup> Current locomotive maintenance practice is that heavy general maintenance takes place roughly every 5 years or 1,000,000 km with an intermediate repair halfway through that period. One might expect a modern locomotive that has had a satisfactory intermediate repair to run for several years before requiring other than routine maintenance attention. An older steam loco would need more frequent heavy repairs.

by an independent boiler inspector and the proprietor of Israel Newton and Sons, a Yorkshire boiler company. The ITT was written in April 2005, specifying the “challenging” closing date of the end of May 2005. Completion of the work was specified as “by Easter 2007” (presumably 5 April).

By normal engineering industry standards, the ITT was an unsatisfactory document, being a melange of an output specification, a process specification and terms & conditions. In some places it was very vague, such as where it said that “*both sides [of the outer firebox] to have new half sides up to a distance of 2 – 3 ft*”. Much of the document was devoted to terms and conditions, such as the need to maintain “*a complete file of the most stringent and comprehensive nature, combining all the elements referred to above and recording every aspect of the rebuild; its specification, materials and workmanship will be required by the museums VAB giving the highest levels of traceability and accountability.*”

Three tenders were received, from Riley and Son, L&NWR Crewe, and McEwen Boilermakers. The quotations were assessed by the museum by 8 June. A draft contract was produced by Dennison Till (on behalf of the museum) and this was approved and officially submitted to Riley and Son on the 28 June and duly signed by them. However, following submission to the Heritage Lottery Fund (HLF), it was not until 19 September that the HLF sent form PM1 to the Museum granting permission to start work.

As work progressed, dismantling reached a point where a stage inspection took place which led the VAB boiler inspector to declare further work was required to the boiler. This resulted in a substantial increase in the cost of the overhaul and, on 1 December 2005, the Museum issued an instruction to Riley and Son to stop work on the contract. Riley and Son wrote to advise the costs of the additional work now required, which was £207,000 with a rebate of £40,000 for contracted works negated by the extra works now required. The newly found faults were:

- ◇ Foundation ring heavily corroded and cracked
- ◇ Outer firebox wrapper plate heavily corroded and thinned
- ◇ Copper firebox wrapper plate heavily caulked and thinned
- ◇ Copper firebox throat plate heavily caulked and thinned
- ◇ Steel firebox throatplate heavily corroded and thinned

Riley and Son pointed out that the project was now slipping badly that they were heavily dependent on the ability of their sub-contractor R.K. Pridham Engineering of Tavistock (now part of South Devon Railway Engineering Company<sup>f</sup>) for supply of pressed parts.

With the rising cost of refurbishing the A3 boiler, the NRM investigated whether it would be better to stop work and either refurbish the A4 boiler, or buy a new all-steel replacement boiler by the German boiler works at Meiningen, which at that time was engaged on the construction of a very similar boiler for the new A1 locomotive then under construction.

Following 6 weeks of deliberations, on 12 January 2006, the NRM issued an instruction to Riley and Son to restart work. Difficulties however arose with the supply of flanged plate-work from their sub-contractor, Pridham. From the correspondence of this period, it is unclear whether Pridham was working as a sub-contractor of Riley and Son or a separate contractor reporting to the NRM as, by October 2006, the Head of Knowledge and Collections at NRM was corresponding directly with Pridham. Eventually the Museum took responsibility for the order from Pridham for the purchase of the necessary copper sheet from the South Devon Railway.

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<sup>f</sup> This firm is no longer trading, the assets having been sold and relocated to the South Devon Railway (SDR) (without any liability or warranties for previous works) in September 2010. The SDR also took on Pridham's staff under TUPE.



This NRM order (Reference: MJH 398677) was placed with the South Devon Railway on 8 February 2007 and, in line with the stated 16 -18 week delivery period (including due process of certification), the copper plate was delivered to Pridham's Tavistock works on 13 June 2007.

The situation continued to deteriorate and, by April 2007 (the original completion date), Riley and Son stated that work on the boiler was at a standstill due to any lack of response or supply from Pridhams. The situation was viewed as “disastrous” and the NRM consulted their legal advisors. This produced a response from the MD of Pridhams explaining in part that the situation was due to pressures of other work which had caused them to decline to tender for the boiler repair in the first place, together with the delays and backlog in customer orders caused by the removal of the entire business to Pridham’s new premises in Tavistock. Furthermore, as stated above, the plate was not available in April and was delivered in June.

During the summer of 2007, progress on the boiler had all but ceased and it was proving impossible to get any communication from Pridham regarding supply of components. At this stage the NRM appointed a contract manager, on loan from the Science Museum. A joint meeting was held at Pridhams works involving staff from Riley and Son, following which Riley and Son were requested to despatch components including the boiler barrel sections and the fireboxes by road to Pridhams in Cornwall. The NRM files are incomplete on much of the activity at this time, but an email indicates that discussions were taking place during June 2007 on the necessary steps and adjustments required to transfer part of the contract to Pridhams, and a contract variation was issued some time later. Eventually Pridhams produced a quotation for the works which was forwarded to the contract manager in late February 2008.



*Figure 2: Trial fit of boiler at Riley and Son (Photo: NRM)*

Later in 2008, boiler components were returned to Riley and Son, only for them to discover that there were a number of cases of defective workmanship including misaligned rivet holes and defective welding. Much of the completed work had to be returned to Pridhams for rectification and re-welding. It was 2009 before any meaningful work resumed at Riley and Son and the repairs on the boiler were finally brought to completion with the successful hydraulic test on 17th February 2011 followed by steam testing on the 21st February 2011 – almost 4 years after the contractual completion date.

## **8.2. Frames and running gear**

In parallel with the saga of the boiler, the NRM was also having to contend with problems in the frame and running gear. These are not unexpected for a locomotive of this age which has seen intensive heavy use throughout its almost 90 year life. Most were of a relatively minor nature, but without doubt the most serious problem to surface had been the discovery of a large

number of latent fractures throughout the whole of the locomotive's frame assembly. An estimate by the NRM Engineering Manager was that repairs to these components had cost more than £0.5m and added 8 months to the duration of the project.

The defects had undoubtedly existed for a considerable time and had steadily developed throughout that period. Had the refurbishment project been properly planned, there would have been a survey at an early stage that would have identified the cracking. Given the extent of these fractures to various frame stretchers and horn blocks, they should have been capable of detection at a very early stage of the repair, and certainly subsequent to the frames being shot blasted back to bare metal. Once one or more cracks had been detected a far more diligent exercise should have been undertaken to examine the whole of the frame structure to assess the extent of the problem, very much as was eventually carried out following the detection of cracks in June 2010. A careful examination of the stripped frame using modern non-destructive testing (NDT) techniques would undoubtedly have revealed the defects. One NRM manager commented:

*“The initial defects to the horn blocks<sup>g</sup> and frame stretchers<sup>h</sup> were noticed at Riley and Son’s works; suspected cracks were investigated and the trail of defects followed until conclusion. This work necessitated the complete strip down of the frames, with the exception of the removal of the cylinders and drag boxes. All components were NDT tested and repaired and renewed as appropriate.*

*“With regard to finding the defects in the horn blocks, stretchers and motion brackets – this was met by all parties with almost disbelief and extreme disappointment. Clearly there was great concern from the NMSI Trustees and all involved at the NRM. Our Contract Manager worked very hard putting a provisional programme for repair together with Riley and Son. He was put under great pressure from the Director to deliver the programme and costs within a few days. Unfortunately this provisional information was then cast as the final version of the programme and the Museum had again set a deadline for completion without consideration being given to further defects being found and the complexity of the loco’s restoration.”*

Because there was no investigation of the frame condition at the appropriate time, the cracks and misalignment were not discovered until the locomotive had been reassembled – which necessitated another strip down and further delays. The NRM manager continued:

*“As work progressed on the remedial work to the horn blocks and frame stretchers, further repairs were also carried out to spring hangers, spring hanger frame stretchers, middle cylinder block, valve gear, running plates, splashers, lubrication system, wheel sets, tender air brake system, cab, valve spindles and valve heads, piston rods, renewal of the main frame doubling plates, renewal of the three motion brackets, renewal of one coupled wheel axle box, complete overhaul of the remaining five coupled wheel axle boxes, horn block wedges and fixings. The frames had to be realigned and temporary adjustable frame stretchers were made to support the frame plates during this process. The frames were noted to be considerably out of alignment. Clearly this process could not be rushed and careful measurement and adjustment were needed to ensure correct alignment.*

*The recent problem with the horn ties was only apparent when the partially finished horn ties were “offered up” as the horn ties have to be finished and fitted before any final machining*

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<sup>g</sup> Horn blocks are the framework on the chassis that support the axle bearings (see Figure 3).

<sup>h</sup> Stretchers are the cross-members in the chassis that support equipment and provide the interface with the front bogie (see Figure 4).

*work is carried out on the horn block. As this has to happen sequentially it has had a knock on effect on the setting up of the axle centres, finishing of the axle boxes horn faces and boring of the crowns.”*



Figure 3: Newly-installed horn block (Photo: NRM)

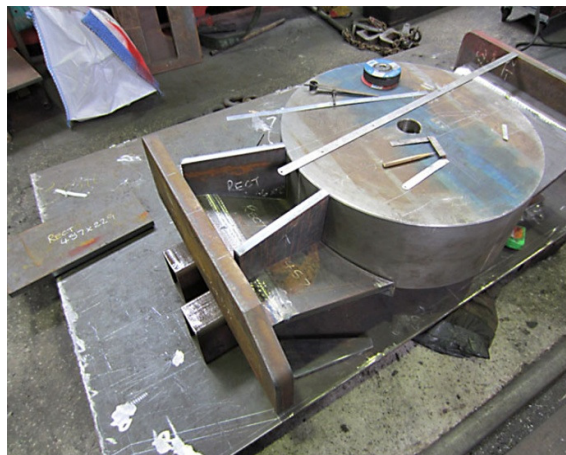


Figure 4: Components of bogie stretcher in manufacture (Photo: NRM)

## **9. NRM Engineering capability and organisation to undertake the restoration**

The successful completion of a project such as the recovery of *Flying Scotsman* to first class running order is largely dependent on the quality and experience of the staff, and indeed contractors, who are involved in the conduct of the project. This project may not have been recognised as such at its outset, but it was one of the most extensive overhaul and renewal projects undertaken in the heritage railways sector. Whilst there have been many restoration projects undertaken by the sector, the effective reconstruction of a large main line locomotive to standards suitable for intensive use, is something which requires the skills and knowledge of a very small number of individuals in the UK. As a people-dependent activity one of the issues which required investigation was the knowledge and abilities of the staff involved in the management of this project.

### 9.1. NRM engineering management

The initial management structure for this refurbishment was:

**Head of Museum**

**Head of Knowledge and Collections**

**Curator of Rail Vehicles**

**Lead Technician**

Not long after the overhaul commenced, the Curator Rail Vehicles left and there was a 4-year gap before the appointment to the new post of Engineering and Rail Operations Manager; he subsequently suffered health problems causing further gaps in supervision. The Head of Museum was also transferred at short notice to SMG in London.

There was consideration of establishing an advisory team to help monitor progress. But, as the Head of Museums said when interviewed:

*"You will recall the atmosphere in which we took on the project. Any number of 'experts' were keen to tell us how to do the job, usually from the basis of a poor track record themselves or a vested interest. We were keen to get the engine out of the public eye and to be left to get on with the job away from the 'hype'. The risk was that any advisory group would degenerate into a futile debate about boiler pressures, smoke deflectors and liveries with little focus or consensus on the real issues."*

The Workshop Supervisor and Lead Technician had been involved in the overhaul of *City of Truro*, which had been completed in the same year as *Flying Scotsman* was purchased. The Lead Technician had been involved in the main line maintenance and operation of *Green Arrow* (and *Flying Scotsman* under previous ownership). Shortly after the Workshop Supervisor retired, the Curator Rail Vehicles made it clear to the Head of Museum that the locomotive could not be completed in the timescale required particularly as other work had been requested of the workshop (operation of *Rocket*, *City of Truro* etc.). HOM authorised the appointment of 2 fitters to be paid from the project budget and at that time an experienced machinist was appointed, as was an additional fitter, who had experience of steam on Rhodesian Railways. Two other members of staff were added to the team after the appointment of the Engineering & Rail Operations Manager in October 2009.

Subsequent to the retirement of the Workshop Supervisor, The Lead Technician applied for the new position of Chief Engineer and was appointed in late 2005. As such he came to be the lead engineer on the project following the departure of the Curator Rail Vehicles. Work commenced on stripping the locomotive and dispersal of such items as the boiler to appointed contractors. This situation continued until the appointment of the Engineering and Rail Operations Manager in October 2009. Upon taking up post the Engineering Manager found a somewhat unsatisfactory situation, which he has described in an interview:

*"I was advised by the Acting Director National Railway Museum, that my top priority was to complete 4472's overhaul as soon as possible. I briefly looked at the loco frames and tender in the workshop. ... My first impression was that there was no system of work; work had been carried out in a haphazard manner and loco parts had been scattered all over the works. [I was advised] that the VAB (Delta Rail), had regularly inspected the loco and all was in order. ... At the time of my appointment, a Project Manager was also appointed, he was the 5th or 6th Project Manager involved with 4472."*

*The Chief Engineer started to distance himself from any involvement in the programme/task planning; he stopped attending meetings and had a negative approach to any form of planning the frame/ancillary fittings programme and visiting/working at Riley and Son. It was clear, even after a few weeks, that the Chief Engineer was not giving instruction to the workshop staff and they were getting frustrated with the lack of direction.*

*Most members of staff were reluctant to discuss the project other than to say words to the effect that the project was a “disaster”. I was told that various tasks had been completed but when it came down to producing paperwork such as NDT reports and material certification, this was not the case. In addition it became apparent that a VAB was not formally engaged to oversee the overhaul.*

*There was so many items of work that were incomplete: valve gear, lubrication system, repair to running plates, pipe work, tender overhaul, brake systems, coupled wheel sets, middle connection rod big end strap. It took longer than expected to gain a full appreciation of the tasks that needed to be carried out to achieve Network Rail readiness. Loco parts were being constantly moved around the workshop; parts had become lost, loaned to other locos; parts had been removed from the loco and not inspected and placed in the stores van and forgotten about. There was a vast amount of time being wasted looking for parts and starting overhauling parts that should have been properly assessed when they were removed from the loco.*

*I viewed progress as slow for a number of reasons: not enough fitters and machinists working on the project, no project direction, lack of motivation and poor staff morale, lack of leadership and imposed fear by the Chief Engineer. The working atmosphere was one of being very “unionist” in approach. There was no sense of urgency and a sense of entrenched laziness. Tackling this problem was always going to be difficult and I was going to need support from Senior Management.”*

It is clear that the loss of Curator Rail Vehicles and the Workshop Supervisor, led to a degradation of the engineering resource available to the Museum. This problem was compounded by the time elapsed before it became apparent that the new Chief Engineer’s depth of experience and project management skills were not appropriate for a project of this magnitude. This was not resolved until the appointment of the Engineering Manager in 2009. Unfortunately during this interim period this lack of experience and in-depth knowledge was to lead to a failure to detect fundamental defects in the locomotive’s frames which would subsequently cause considerable additional costs (and embarrassment) to the Museum.

## **9.2. Professional engineering skills**

For routine repairs and maintenance of a museum exhibit, mainly craft or technician skills are required. By contrast, the refurbishment of a 70-year old locomotive to a condition suitable for regular operation on Network Rail, requires technical leadership either by exceptional individuals with long experience in the sector or by an engineering team with Chartered Engineer qualifications. While many heritage railway organisations rely on one or two experienced and charismatic individuals, this is not a strategy appropriate for a national organisation.

The NRM appears not to have recognised the need for a professional engineering team, as opposed to a skilled workforce in the workshop.



### **9.3. Managing subcontractors**

Managing subcontractors is a large part of the workload of project engineers – an activity that some of NRM engineering team tried to avoid. The skills necessary to manage work being done by others is quite different to those needed to do the work oneself but NRM appears to have recruited a team for the former, while the workload on this refurbishment was largely the latter.

The major overhaul of a worn out steam locomotive can never be considered to be easy, straightforward or cheap. Unless the locomotive owner possesses significant resources, such work will always depend upon a diverse collection of specialist small contractors who collectively form what is little more than a large cottage industry. This is in no way disparaging, for that very industry has many significant achievements to its credit, but it is a simple fact that the British steam locomotive industry which employed tens of thousands of skilled workers using assets worth many millions of pounds is long gone, and what now remains has possibly fewer than one hundred suitably skilled workers with assets to match. There is only a handful of companies which are capable of the full overhaul of a locomotive such as that which the Museum set out to undertake on locomotive 4472, and few (if any) have the project management resources to undertake contracts within the sort of T&Cs the museum attempts to impose on its contractors.

### **9.4. Using non-railway subcontractors**

The 1968 Transport Act encouraged BR to work with the Science Museum to develop a National Railway Museum to house their ever-expanding collection and, seven years later, the NRM was opened in York. At that time, there were still many railway workshops capable of maintaining steam locomotives but, over the years, most have been closed or taken-over by companies such as Alstom or Siemens and converted into hi-tech facilities to support modern train fleets. The only railway workshops where steam locomotives can be maintained are in the heritage sector.

With such a small base of specialist heritage railway contractors, there is a strong incentive to involve the general engineering industry. There is no doubt that manufacture of many of the components and assemblies, such as the axlebox (Figure 5) or brackets to support valvegear and associated mechanisms (Figure 6) could equally well be undertaken by any number of contractors in general industry, all operating to ISO 9000 quality systems and accustomed to working to formal contracts.



*Figure 5: Machining axlebox (Photo: NRM)*

There may be certain techniques, such as assembling white metal bearing housings, that require specialist craft skills no longer used in general industry, but these are relatively few and far between.



Figure 6: Machining motion bracket (Photo: NRM)

Anecdotal evidence shows that attempts to involve general engineering companies in steam locomotive refurbishment have frequently been unsuccessful and it is worth analysing why this might be so.

The challenge of using general industrial subcontractors is that, because they have no background in the application, they would expect to be given clear, precise and unambiguous instructions. Statements such as “*both sides [of the outer firebox] to have new half sides up to a distance of 2 – 3 ft*”, quoted in Chapter 8, would be totally inappropriate. Contractors would be looking for proper engineering drawings, in CAD formats that can be readily translated into CAM (computer-aided manufacturing) files, correctly toleranced, with unambiguous material, surface finish and heat treatment specifications (all preferably in SI units).

This would require a type of professional engineering expertise that, currently, the NRM does not possess. It would involve measuring and analysing the component to be replaced and the loads it would have to carry, recreating it as a CAD file, possibly redesigning some of the internal details to be compatible with modern manufacturing techniques, checking by finite-element analysis that it could carry the loads and, finally, producing a detailed component specification to be sent to potential subcontractors.

A culture change of this magnitude would be difficult and expensive but might be considered as an option in a wider review of how the museum operates.

## 10. Project management and project ‘drift’

### 10.1. Contract management

Throughout this investigation, the subject of project management of contracts has been mentioned by many of those interviewed. It was first strongly commented on by the former Head of Museum who had this to say:

*“I’ve noted the weaknesses in our organisation of the overhaul and I would add one other related point. It could be argued that our own weakness was a shortage of sufficiently skilled and experienced people in-house to carry the project forward once a key member of staff left. But the same problem repeats nationwide. We had wanted to go to contract for the restoration works on the boiler but there are simply no contractors out there who can apply the necessary skills and work within robust contract disciplines. Private owners, in my experience, work with contractors on nothing much more than a handshake. A public body like the NMSI wants robust contracts and finds it difficult to work effectively without them.”*

*In my view, we should be seeking ways of improving contract management skills in the heritage restoration industry. This has happened in the heritage building field but has yet to make much progress in the field of steam.”*

This is a clear summary of one of the major factors which has caused problems during the course of this project. SMG has a number of staff that are well versed in the institution and management of contracts and that the NRM would wish for all of its contracts to be managed in what might be termed a professional manner. Unfortunately the major *cottage engineering industry* which supports the heritage railway movement possesses no more than a very small (low single figures) number of company managers who have any significant experience of the management of contracts in any way approaching normal modern commercial discipline.

While NRM might hope for the heritage railway industry to implement more formal project management and reporting structures, this is unlikely. It is an industry that consists of a network of small organisations trading with each other, many of which rely on semi-retired people or volunteers for part of their workforce.

As discussed in Chapter 9, it would be possible to expand the base of potential suppliers by making more use of the general engineering industry; however, with the present NRM engineering organisation, this would not be practicable.

In these circumstances, the adoption of more stringent contractual terms in dealings with subcontractors is unlikely to reduce the probability of contract failure. Based on the evidence of *Flying Scotsman*, the sector does not have the resources to adopt more formal procedures and NRM does not have the engineering strength to support that model of project management.

## **10.2. Conflicts between conservation and standards for main-line operation**

Projects of this nature inevitably require the renewal of sometimes quite large sections of material from the structure of the locomotive. This has been part of the ongoing life time repair history of the locomotives where boilers were exchanged and renewed as were cylinders, wheels, valves, pipework and in some cases entire main frames. Very few locomotives such as *Flying Scotsman* consisted of more than a small percentage of their original components by the time that they were withdrawn from service, often 40 years after construction.

Operation of main line steam locomotives on Network Rail places heavy demands on the equipment. Many sections of track are loaded close to capacity and inter-running a 75 mph steam locomotive, with a service of 120 mph, high acceleration electric trains requires the steam loco to be able to provide its full performance whenever needed.

This requires close attention to detail and ensuring that the structure and power systems of the locomotive are in first class condition so it can endure the rigours of such operation. This is vitally necessary to ensure safety of operation and that the locomotive can adequately perform its duties without causing delay and disruption to other services on the network.

To many of the private owners operating steam locomotives, and their supporters in the heritage railways community, the replacement of significant parts necessary to maintain their locomotives presents no real problems of conscience. Nevertheless from a museum conservation point of view, there is a concern that original fabric should be retained wherever possible. In discussing the HLF bid it has already been noted that the Head of Knowledge and Collections said that *“The Curator of Rail Vehicles was sceptical at the time but the task was to do the most necessary work and re-use as much as possible in order to keep the cost down.”* and it was against this background understanding that a number of components were reused when they really required replacement.



### **10.3. Marketing vs. Restoration**

It is apparent that, aside from its iconic status as “The World's most famous steam locomotive”, No 4472 was very much seen as a major commercial opportunity by the NRM marketing team and the project was framed as a commercial activity. Indeed the HLF submission had a high percentage of the project total dedicated to display and marketing arrangements with a fixed proportion of the total assumed funds allocated to the overhaul. As such it is difficult to avoid the conclusion that the overhaul was initially driven by marketing forces, which were, in all probability, totally unaware of the technical difficulties which lay ahead. There also appears to have been a failure by management to impose a realistic balance between the two activities.

It is recognised that the NRM faces strong pressures from the rail enthusiast community to make “the people’s locomotive” available for events, such as those at Barrow Hill, Chesterfield.

However, NRM management needs to balance the need to satisfy its client base with the need to ensure an effective engineering overhaul.

### **10.4. Project drift**

It is difficult to analyse drift in the project because there was no real plan against which it could be measured and new tasks were added to the workload as new problems were uncovered.

There was, however, specification creep. In particular, following a campaign by the specialist press, it was agreed to refit vacuum brakes to the locomotive, so it could haul Mk I rolling-stock on preserved lines.

## **11. Engineering capacity to maintain and operate the locomotive**

Maintenance and operation in the (non-heritage) rail industry, like most engineering asset management systems, is heavily based on formal structures. One expects to see mileage-based or time-based examination and maintenance schedules, process specifications for maintenance operations, fault-reporting systems, routine test schedules, non-conformance reports, hazardous incident and near-miss reporting, etc. This is backed-up by performance analysis looking at trends in data that determine when more significant maintenance interventions need to be made. Components have serial numbers and records are kept of test results, when they are fitted or removed from a vehicle and their distance/time in service. This work is managed by a professional engineering team; the VAB is seen as an additional audit or check on what is done, not a fundamental part of the process.

The NRM does not appear to have similar systems in place. If the objective is to maintain a static collection with very occasional operation of locomotives, then perhaps they are not needed but, if the NRM’s intention is that *Flying Scotsman* runs regular excursions and special trains, a more formal structure is needed. Based on evidence from the interviews, this type of working would have been very different from the culture then existing.

It is not possible to comment on the capacity and competences of the present NRM workshop team to maintain *Flying Scotsman* without knowing what other locomotives they will be expected to deal with. It is worth noting that the maintenance demands of an operational locomotive will inevitably reduce the capacity of the current team to carry out further overhauls without augmentation of the team. If the present refurbishment is successful, then the maintenance workload should be manageable with a team of the present size, if appropriately organised. However, consideration should also be given to the demands placed on the engineering management resource made by the need adequately to monitor and audit the condition of other locomotives which are currently on operational loan at diverse locations around the UK.

## 12.Future NRM engineering core competences

The recruitment and retention of competent staff is of great importance to the maintenance of the operational competence needed to keep the locomotive in operation during the coming years. The formal training of engineers in the discipline of steam locomotive engineering has long since ceased, and, to a large extent, now depends almost entirely on engineers from a variety of backgrounds who have become involved with the preservation movement and gained relevant knowledge and skills. Some of the leading workshops have, in recent years, been involved in the training of young people and this has produced a small number of outstanding people who could become the leading figures of the preservation movement in years to come, but there are not enough to go round.

The significant investment which the museum has made in the acquisition and repair of *Flying Scotsman* will produce a locomotive which will require careful control and husbandry in the coming years if this investment is to be protected for the benefit of the museum. There is every reason to expect that the refurbishment will mean that the locomotive should be able to remain in use as a main line locomotive for at least the next twenty years, given periodic examinations, replacement of worn parts and boiler overhauls carried out at the correct intervals.

The Museum must establish and maintain suitable training and succession policies to ensure that it has the right engineering and operational staff successfully to carry through the management of the locomotive that will be star attraction of the museum for a long time to come. It has already made an important step in the recruitment of an Engineering and Rail Operations Manager with significant experience and knowledge of the maintenance, operation and repair of steam locomotives engaged on main line work.

There are two important questions that NRM senior management needs to address:

- ◇ How much future refurbishment work – and what type of work – will be carried out in-house and how much will be subcontracted to other companies?
- ◇ Is the intention to rely on the “heritage railways industry” to provide engineering services or will the wider engineering industry be involved?

Chapter 8 described the boiler restoration where large components were transported around the country between York, Bury and Tavistock. It is not obvious that this was a sensible division of responsibilities. Whether this work breakdown was adopted to ensure that there was always something for visitors to the Museum to see, or whether it was felt to be the best way to complete the refurbishment at minimum cost and timescale is not known.

The NRM has in place formal contracting arrangements but, as has been shown in the refurbishment of *Flying Scotsman*, these are worse than useless (in that they give a false sense of security) unless backed-up by a professional engineering team capable of producing rigorous specifications and a network of potential suppliers able to undertake the work and meet the required contractual and engineering standards.

As discussed in Chapter 9, the heritage railways sector is likely to remain a collection of geographically-distributed jobbing shops, many linked to preserved railways, with an ageing workforce and that relies on informal “handshake” contracts, rather than formal documents drawn up by legal advisors. If NRM insists on the need for competitive bidding, traceability and accountability, intrinsic to a UK public sector organisation, it is difficult to see how it can continue to rely on the heritage industry, to the extent attempted during the refurbishment of *Flying Scotsman*.

This implies that **either** the NRM needs to build-up its core engineering competence to carry out a greater proportion of the work in house **or** it requires the competence to be able to contract professionally with general engineering industries. In the latter case, the NRM would need a team of professional engineers who are at home using CAD to design and stress components and who are able to work in the contractual environment demanded by a 21<sup>st</sup> Century state-funded organisation. In turn, this would change the skill set needed by workshop staff – less emphasis on the ability to use a milling machine and more on the ability to use NDT or metrology equipment.

### **12.1. Systems engineering**

The track standards on modern main lines are very different to those for which heritage locomotives were designed. As an example, while the absence of rail joints reduces transient vertical forces, it could well increase wheelset yaw forces as the wheelset does not have to ability to “reset” itself every 60 ft as it goes over a joint. The consequent quasi-static yaw forces in cornering, applied to horn blocks and longitudinal chassis members, could well increase the stresses to levels for which the locomotive was never designed and which were never experienced when the locomotives were new.

Apart from the ability to restore a locomotive to the condition it might have been in half a century ago, NRM should consider whether it needs the ability to analyse how it will function in the new conditions to which it is subject. At present there appears to be no competence in this area.

## **13. Conclusions and key findings**

During this investigation, many documents have been reviewed, and, in interviews with those involved, more than 200 questions have been discussed. It has proved difficult to find information on certain aspects of the project, in particular details of specifications and estimates for much of the engineering work. It has not been possible to discover any original programme for carrying out the repair that justifies either the published timescale or the budget. From all this information it has become apparent that the salient points relating to the cause of the difficulties include the following:

- ◇ There was a clear, pressing and very high level intent that the locomotive should be secured for the nation and there were significant concerns that it would be sold to a foreign buyer.
- ◇ It was known that the locomotive was in an extremely worn out condition.
- ◇ The pre-purchase inspection by AEA Technology confirmed the worn condition, due in part to the recent heavy workload of the locomotive, but was unduly optimistic about its overall condition.
- ◇ A professional valuation was obtained which suggested a very high value for the locomotive. This document also said the condition of the locomotive was “generally sound” and stated “The locomotive has proved to be as powerful and reliable as any steam locomotive presently operating on the Network Rail system”.
- ◇ The museum did not make an adequate assessment of the state of the locomotive after purchase. Consequently there was never a credible refurbishment plan and new faults took staff by surprise, even 5 years after purchase. Inadequate attention was paid to the detailed examination of the locomotive structure once it was stripped down. In

particular, serious latent defects in the locomotive frame were not detected, resulting in extensive, costly and embarrassing rework.

- ◇ The museum's team responsible for the overhaul suffered disruption and discontinuity due to illness and staff turnover. This led to a degradation of the project team's capabilities and knowledge of the standard of work necessary to complete the overhaul satisfactorily. It seems likely that budget constraints and an over-optimistic view of the capabilities of individual team members, constrained the Museum from making the necessary staffing changes to resolve this problem.
- ◇ There were conflicts between the needs of conservation, to retain original material within the locomotive structure, and the need to replace items which were not fit for operation on the main lines of Network Rail.
- ◇ Defects in the A3 boiler were underestimated at the time the refurbishment contract was awarded. Problems arose with the contract when the work necessary to repair the boiler was found to be far more than at first predicted. This resulted in difficulties in the customer/contractor relationship and eventually led to the contract terms being recognised as unworkable and consequently suspended.
- ◇ The history of this project has seen a number of similar reverses due to the discovery of further defects, which have in turn required significant additional funding.

There are a number of strategic issues that have been observed during this investigation.

- ◇ Maintaining a fleet of locomotives in a fit state for demanding mainline operation on Network Rail requires a different type of structure, organisation and mix of skills to running a museum. In particular, it needs a more formal structure of vehicle inspections, maintenance and fault reporting and greater competence in railway systems engineering.
- ◇ The supply chain with experience in the refurbishment of heritage rail vehicles consists of an informal network of small companies. The formal contract management procedures considered essential by NRM to meet the competition and transparency requirements of organisations applying for public funds are incompatible with this supply chain. This situation could be ameliorated by changing the balance between in-house and contracted-out work.
- ◇ It would be possible to bring other firms into the supply chain but this would require a major expansion and change of mission of the NRM engineering group. Otherwise it would pose a significant risk.
- ◇ In the wider UK rail industry, a VAB (vehicle inspection body) is seen as a check on what is being done, not the design authority for the work. In the refurbishment of *Flying Scotsman*, it appears that a VAB has sometimes dictated the work. It has not been clear where engineering accountability for the project resides.

It is recommended that NRM considers the scope, size and responsibilities of their project management and engineering functions, and their contracting policy, in the light of these observations.

## 14. Appendix: List of people interviewed

Director NRM

Former Head of Museum NRM

Head of Collections and Knowledge NRM

Engineering and Rail Operations Manager NRM

Former Rail Vehicle Collections Manager NRM

Principal Engineer Lloyds Register Rail Ltd (Network Rail VAB) formerly of AEA Technology

Managing Director Riley and Sons (E) Ltd

Director of Swindon Railway Workshop Ltd

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## References

<sup>1</sup> Letter from Steve Davies MBE, Director NRM, on behalf of Chris Swinson, SMG Trustee and Chair SMGAudit Committee, 10th January 2012

<sup>2</sup> [http://en.wikipedia.org/wiki/LNER\\_Class\\_A3\\_4472\\_Flying\\_Scotsman](http://en.wikipedia.org/wiki/LNER_Class_A3_4472_Flying_Scotsman)

<sup>3</sup> *Steam Railway* No 405, August 2012, pp 46-53. Published by Bauer Media.

<sup>4</sup> *Steam Railway* No 406, September 2012, pp 85-91. Published by Bauer Media.

<sup>5</sup> Valuation of Flying Scotsman as of 26 February 2004 written by Bill Parker, Swindon Railway Workshop Ltd. Registered Address: The Flour Mill, Bream, Lydney, Gloucestershire, GL15 6HT

<sup>6</sup> Report AEATR-TEP-2004-173 Issue 1, Locomotive No. 4472, Flying Scotsman Condition Assessment, February 2004.

<sup>7</sup> An independent review into the broader issues surrounding the loss of the RAF Nimrod MR2 Aircraft XV230 in Afghanistan in 2006, Charles Haddon-Cave QC, Report HC 1025, The Stationery Office, London, October 2009.

<sup>8</sup> <http://news.bbc.co.uk/1/hi/scotland/3495733.stm>

<sup>9</sup> 'Flying Scotsman' - A Review of the Condition of the Locomotive and Work Undertaken from arrival at York 28/5/04 up to 7/10/04