First Class Partnerships
Rail Consultants

Final Report on the Independent Review of the Proposed Programme of Works in the Restoration of the *Flying Scotsman* Locomotive 4472

Reviewers : AD Roche FREng, FIMechE, BSc. Hon. DTech.
: AC Baker CEng, FIMechE

For the Attention of

Mr J Newby,
Chief Operating Officer,
Science Museum Group

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Executive Summary

1 Locomotive number 4472 *Flying Scotsman* was purchased by NRM in April 2004 and following a short period in operational service it was withdrawn in December 2005 for a major overhaul. This 'Heavy General' overhaul was planned to be completed in one year and at a cost not to exceed £1m. Approaching seven years later and with expenditure in excess of £2.7m, a submission has been made by NRM for further funding to complete the restoration work.

2 The Board of Trustees, Finance & Strategy Committee have requested independent high quality engineering advice and support to provide the following:

- Verify (or otherwise) the assessment of the work required to complete the locomotive
- Provide independent advice direct to the Finance & Strategy Committee on the methodology proposed and of the veracity of the preferred solution.
- Continue to provide advice to the committee up to the point of completion

3 First Class Partnerships Ltd has been contracted to deliver this assignment and it has been undertaken by two senior Chartered Mechanical Engineers, Tony Roche and Allan Baker, both with extensive careers in the maintenance of railway rolling stock. The independent investigation commenced on Monday 15th October 2012

4 The work required to complete the restoration has been separated into 15 separate work packages by the NRM, with the potential for these packages to be carried out either in the NRM workshops or by a private contractor experienced in heavy maintenance of steam locomotives.

5 The work carried out over the past seven years has taken place at the NRM and at a number of locations and/or by several contractors. In order to establish a definitive record on the detail and extent of this work, NRM staff were requested to compile a document as to where, when and to what standards the work has been completed and where relevant, had it been certified to meet Railway Group Standards. They were also asked to determine if it is fit for purpose. This work was completed on 30 November and it has not only allowed us to perform a detailed audit, but has also provided a baseline to determine the outstanding restoration work required

6 The NRM inventory of material and components required to complete the restoration work comprised 85 items. Physical checks have verified the location and condition of 83 of these items and the two outstanding ones are of a minor nature and are easily replaced

7 We have examined the unfinished locomotive and tender at NRM in the condition it is currently in and held discussions with NRM management reviewing the work packages. In addition we have visited two contractor workshops that have substantial experience of this type of work and had discussion with the Managing Directors of those Companies to establish best current engineering practice for this type of work.

9 We are in agreement with the proposed work packages 2 to 10 and 12 to 15. In the case of package 11 (bogie repairs) it was established that Non Destructive Testing (NDT) had not been carried out on the bogie frame structure. This is an essential test to confirm or otherwise that the frames are free of fractures and the NDT work was added to the scope of work for this package.

10 *Flying Scotsman* is an LNER Gresley design class A3 locomotive with two outside cylinders and a middle cylinder and work package 1 relates to work on the middle cylinder. Currently the middle cylinder bore is misaligned longitudinally and vertically in relation to the engine frames. The cylinder is therefore, not correctly positioned on the side frame members and there are a number of packing shims between the cylinder and the side frames. In addition the there is a variation of 0.44 inches on

the length the bores on the three cylinders and care will need to be taken when the engine is reassembled to ensure that sufficient clearance exists on each cylinder between the piston head at the end of its stroke and the end of the cylinders.

11 In accordance with Gresley design, A3 class locomotives should have a cylinder liner bore diameter of 19 inches. The bores on all three cylinders fitted to the locomotive currently have been measured, with the middle and left-hand side cylinder bores being 20 inches and the right-hand side being 19.5 inches. The combination of 20 inch diameter cylinder bores and the A4 class boiler working at 250lb pressure fitted to the *Flying Scotsman* for a long period of time prior to its acquisition by the NRM, has allowed the locomotive to be operated at substantially above its design characteristics. This, along with the middle cylinder misalignment, is in our view, the principal cause of the seriously deficient mechanical condition of the locomotive, discovered during its current overhaul.

12 Our professional engineering judgment is, that if sustainable reliability is to be achieved for the future operational performance of the locomotive, the NRM proposed treatment of boring out the middle cylinder such that the bore is concentric with the frame, is unacceptable. It is necessary therefore, for the middle cylinder to be correctly installed in the locomotive main frames and for replacement liners to be fitted to all three cylinders and bored to 19 inch nominal diameter. When this work is completed it will allow the locomotive to be operated for the foreseeable future within its design parameters, with good riding characteristics and economical servicing and maintenance requirements. Appendix 4 provides substantial further detailed engineering information on this particular issue.

13 One of the problems encountered during the overhaul is that certain parts of the locomotive frame are not exposed until other components are removed; in several cases this has resulted in additional work being required. A similar issue potentially exists when the middle cylinder is removed, since a relatively small section of main side frames not otherwise visible, will then be exposed. At that point in time, approximately 12 weeks after the restart of the restoration programme, a detailed examination will be made for any fractures or other signs of distress and an NDT test will be undertaken. It is however, considered that the risks of any serious problems in this area are small and any cost of overcoming them, relatively low. Clarification of the position at week 12 of the proposed programme of work will enable an early decision on whether to proceed further with the overhaul before significant expenditure has occurred.

14 [redacted]

15 We recommended that the Finance and Strategy Committee authorise the commencement of contract negotiations with an external specialist contractor. Limited to undertake the required work packages to complete the restoration of *Flying Scotsman* based on the scope of work identified and stated in the documents discussed and presented to [redacted] during this investigation. They are:

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning / [redacted]

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning / [redacted]

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning / [redacted]

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning / Component / Systems Repair Status Document

16 The delivery programme from [redacted] to complete the restoration work, followed by testing and commissioning covers a total period of 60 weeks, compared with 74 weeks for the programme that had been proposed by [redacted]. Depending on approval for contract negotiations to proceed and to be finalised it would result in no commercial operational running in 2013 and probably a reduced programme in 2014.

17 [redacted]

18 If a contract is awarded a specialist external contractor, it is recommended that the NRM should undertake a detailed assessment of its internal resources required to manage the contract. Specifically, enhancing processes for engineering control, contract, project and financial management for monitoring and reporting on the performance on the contract. In particular procedures and processes need to be put in place to control any work this is required over and above the specification as it exists now, along with any associated engineering change.

19 With the substantial level work undertaken on the *Flying Scotsman* by the end of its restoration, the locomotive should be capable of sustained reliable performance in the years ahead. But this will only be achieved if there is a disciplined approach to train diagramming, footplate operation, engineering maintenance and train servicing. All these issues need to be addressed over the coming months before the locomotive completes its commissioning. In our view, failure to do so will place considerable risk on the sustainable future service reliability of the locomotive and its reputation. We have included as Appendix 7and 8 outline operational and steam locomotive maintenance strategies to assist and guide NRM in this regard

20 Our considered opinion is that for operation of steam locomotives, the NRM needs to have available to them, a Chartered Mechanical Engineer, knowledgeable and experienced on steam locomotive engineering, to provide professional technical advice in areas of engineering science over and above that currently available. While such expertise is unlikely to be required with any great frequency, a call-off type of arrangement might well be considered appropriate. A similar situation regarding professional engineering advice would also be appropriate for any other rolling stock the NRM may want to operate.

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1.0 Purpose of the Final Report

1.1 To provide the final report to Mr J Newby, Chief Operating Officer, Science Museum Group on the review of the proposed programme of works for the restoration of the *Flying Scotsman*, locomotive number 4472

2.0 Background Information and Remit

2.1 Following the purchase of the *Flying Scotsman* by the National Railway Museum (NRM) in 2004 the locomotive received a heavy intermediate repair in the NRM workshops and re-entered service in February 2005 in. It was then used on a range of steam hauled passenger services; however unreliability of the locomotive became an ongoing issue.

2.2 It was decided in late 2005 that the locomotive would be given a 'Heavy Overhaul', with the programme of work being focussed on delivery by the NRM workshop team. Some seven years since the start of the workshop repair there remains a significant amount of outstanding work to be undertaken, much of which has a high precision engineering content.

2.3 Expenditure on the restoration programme has risen substantially during the restoration and at October 2012 stands at £2.770m, with additional funding required to complete the restoration programme.

2.4 The locomotive is currently at York and two options have been considered by NRM to take it to completion over the next five-six months, the options being an in-house solution at York, or alternatively using an external contractor. [redacted]

2.5 The assignment remit was to provide the Board of Trustees Finance & Strategy Committee with independent high quality engineering advice and support to provide the following:

- Verify (or otherwise) the assessment of the work required to complete the locomotive
- Provide independent advice direct to the Finance & Strategy Committee on the methodology proposed and of the veracity of the preferred solution.
- Continue to provide advice to the Committee up to the point of completion

2.6 The review has been led by Tony Roche, formerly a British Rail Director of Mechanical & Electrical Engineering and subsequently the Executive Member of the Main Board of British Rail with specific focus on engineering and safety. He is a Past President of the Institution of Mechanical Engineers (IMechE) and a Fellow of the Royal Academy of Engineering. Support has been provided by Allan Baker, formerly an Engineering Director of Angel Trains Limited, who has a lifelong interest and practical involvement in the design and maintenance of steam locomotives. He is a Chartered Mechanical Engineer and a past Chairman of the Railway Division of the IMechE.

2.7 The independent investigation commenced on Monday 15th October 2012

3.0 Methodology of Investigation

3.1 Two assessments have been undertaken to understand the outstanding work required for the completion of the restoration work. The first of these involved the NRM project team compiling a detailed and documented record of all the work that has been done since the restoration began in late

2005. This record is in tabular form dividing the design of the engine and tender into prime systems such as braking, wheels, cylinders, boiler, etc. The prime systems were then broken down in to sub-systems and where appropriate, individual components, details being recorded for each item. This included, when the overhaul work was done, where and by whom, to what standards and had the work been certified as being in compliance with any laid down standards and signed off by the regulatory body to enable a fitness to run certificate to be issued. We have audited these records to provide the necessary base line, thus ensuring that the totality of the required restoration work has been properly addressed.

3.2 The NRM staff were requested to create an inventory of what material and components were required to complete the restoration work. They were also asked, and have retrieved all components and materials relating to the locomotive from [redacted], concentrating storage at the NRM. With all materials and components at the NRM, a physical cross check has been undertaken to establish that everything required is available. We have undertaken a random sample of 10% of the components based on the more critical items.

3.3 We have reviewed the project and programme engineering processes to establish whether the appropriate controls are in place for the delivery of the remainder of the work. The review focussed on a pragmatic programme of work and processes to be put in place to ensure on-going quality control delivers a 'fit for purpose' engineering solution.

3.4 We reviewed the methodology for creating project expenditure forecasts and what control mechanisms are in place to manage labour and material costs during the remainder of the project. The key objective was to ensure financial monitoring arrangements were in place to ensure that spend is in line with the physical delivery of programme elements and in line with any agreed financial budget.

3.5 We have given consideration to the ongoing requirements to continue to provide advice to the Committee up to the point of completion

3.6 A number of visits have been made to the NRM at York and discussions held with the Engineering & Rail Operations Manager and the Project Manager. This has allowed us to examine and review progress on the restoration work, the project programme, the financial forecasting, expenditure control arrangements along with staff resources and competencies [redacted] The package headings are shown at Appendix 2.

3.7 Discussions have been held with Anna Evans, Head of Property and Project Management (North), NRM regarding project management systems and resources. Also with Helen Ashby, Head of Knowledge and Collections, NRM on financial information and control arrangements

3.8 Visits have been made to [redacted] and to [redacted] discussions being held with the Managing Directors of both these steam locomotive repair facilities. The objective was to seek views on best practice methods for the types of work remaining to be completed on *Flying Scotsman*, the necessary engineering competencies to do the work and the importance of optimising quality standards to ensure potential short term and long term engineering and operational risks are minimised.

3.9 A vast array of reports have been reviewed regarding the condition of *Flying Scotsman* over the last 20 years or so. This work has included the 'Meanley Report which has provided substantial information regarding modifications undertaken on *Flying Scotsman* while in private ownership. Engineering discussions have been held with senior engineers involved in the running and maintenance of the locomotive, along with its class mates when it was in BR ownership.

Investigations has been conducted into the original design features of Gresley class A3 locomotives and the various modifications undertaken on them throughout their entire lives, up to the locomotive's sale into private ownership.

3.10 We have had discussions with the Vehicle Acceptance body (VAB), responsible for issuing the various final certifications for operational running on the national rail network. They have confirmed which specific tests need to be satisfactorily undertaken to enable approvals to be given.

3.11 From the commencement of our investigation it was recognised that the principal package of work that needed to be reviewed related to the steam cylinders. The importance of good engineering practice to the alignment, interfaces and bore sizes of the three steam cylinders are critical the effective operation of a locomotive. The engineering explanation of this is given in Appendix 3.

3.12 A specially equipped support coach is required for use with *Flying Scotsman* during commissioning, test load running and mileage accumulation and we have reviewed the planned availability of this. It is also required for the ongoing use of the locomotive on the national network.

4.0 Findings

4.1 The NRM inventory of material and components compiled required to complete the restoration work consisted of 85 items. Physical checks have verified the location and condition of 83 of these items and the two outstanding are of a minor nature and are easily replaced

4.2 Over a period of four weeks the records of all work done during the past seven years were produced by NRM on a system by system basis. Documentation for some 277 separate items, of which there remains 31 to be located and 36 which can only be issued at the completion stage. In conjunction with the Engineering and Rail Operations Manager we performed a physical examination of the *Flying Scotsman* to review what work was required to be undertaken to complete the restoration. The review took cognisance of the records of what work had been previously done and the fifteen packages of work shown at Appendix 2 included in the proposed programme of work we were asked to examine.

4.3 We are in agreement with the proposed packages 2 to 10 and 12 to 15. In the case of package 11 (bogie repairs) it was established that an NDT (Non Destructive Test) had not been carried out on the bogie frame structure. This is an essential test to confirm that the frames are free of fractures and was added to the scope of work for this package.

4.4 *Flying Scotsman* is a Gresley design class A3 locomotive with two outside cylinders and a middle cylinder and Package 1, relates to work on the middle cylinder. Currently the middle cylinder bore is misaligned longitudinally and the cylinder casting itself, vertically in relation to the engine frames. There is evidence of a thin shim having been inserted between the middle cylinder and the right-hand frame plate and there is a slight joggle in the left-hand frame plate between this cylinder and the leading coupled wheelset. While the miss-alignment is relatively small at the cylinder, when transmitted the distance to the journal of the crank-axle on the intermediate set of coupled wheels, it is around a quarter of an inch out of line at the coupling rod big end. This cylinder is very clearly not correctly positioned on the side frame members and the front end of the locomotive's frames are out of line with the result that the new bogie stretcher does not sit square between them. In addition the there is a variation of 0.44 inches on the length the bores on the three cylinders and care will need to be taken when the engine is reassembled to ensure that sufficient clearance exists on each cylinder between the piston head at the end of its stroke and the end of the cylinders. The middle cylinder is slightly out of alignment vertically and whilst it is not entirely clear what effect this has had on the overall problems at the front end of the locomotive, realigning the cylinders will allow it to be addressed and corrected

4.5 In accordance with Gresley design, A3 class locomotives should have a cylinder liner bore diameter of 19 inches. The bores on all three cylinders fitted to the locomotive currently, have been measured. The right hand one having been fitted since the engine has been under overhaul at York. The middle and left hand outside cylinder, along with the original right hand cylinder which has since been removed, have been measured at 20 inch nominal diameter. However, the replacement right hand cylinder now fitted on the locomotive, has a diameter of 19.5 inches. With 20 inch diameter cylinder bores, combined with the A4 class boiler working at 250lb pressure it was fitted with, *Flying Scotsman* was for a long period of time, being operated substantially above its design capacity. This, along with the middle cylinder misalignment, is in our view, the principal cause of the seriously deficient mechanical condition of the locomotive, discovered during its current overhaul.

4.6 Our professional engineering judgment is, that if sustainable reliability is to be achieved for the future operational performance of the locomotive, the NRM proposed treatment of boring out the middle cylinder such that the bore is concentric with the frame, is unacceptable. It is necessary therefore, for the middle cylinder to be correctly installed in the locomotive main frames and for replacement cylinder liners to be fitted to all three cylinders and bored to 19 inch nominal diameter. When this is implemented it should ensure smooth running of *Flying Scotsman* for the foreseeable future. Appendix 4 provides substantial further detailed engineering information on this particular issue.

4.7 One of the problems encountered during the overhaul is that certain parts of locomotive frame are not exposed until other components are removed; in several cases this has resulted in additional work being required. For the removal of doubt, such a potential exists when the middle cylinder is removed, since a relatively small section of the main frames not otherwise visible, will then be exposed. At that point in time, a detailed examination will be made for any fractures or other signs of distress and an NDT test undertaken. It is however, considered that the risks of any serious problems in this area are small and the costs of overcoming them, relatively low. Clarification of the position will be achieved by week 12 of the proposed programme of work and before significant spend has occurred, with the potential for an early decision on whether to proceed further with the overhaul.

4.8 The initial proposed scope of work, [redacted], did not take account of testing, running-in and commissioning following completion of the restoration work. This has now been addressed and is included in the proposed schedule of work.

4.9 [redacted]

4.10 NRM workshops have been in the lead on the heavy overhaul of *Flying Scotsman* since late 2005, though there have been many changes in the management and engineering staff during that time. The plant and equipment available in the workshop is strictly limited as is the range of experiences and competencies of the NRM team relative to the major scope of work that remains to be completed on *Flying Scotsman*. This results in the need for NRM to sub contract significant elements of the work as identified in the proposed work programme. Removal of the cylinders, correction of any issues on the cylinders and the side frame members along with the front buffer

beam, will require significant engineering expertise, the main bulk of which is beyond the experience of the Museum staff. Precise refitting of the cylinders and correcting the frame miss-alignment, along with the other components, is critical to achieving the necessary alignment at the respective component and system interfaces. Management of the supply chain for component supply and repairs along with any sub-contractors is likely to generate many challenges. Internal control and incentives to deliver work packages is essential and from observation, productivity appears generally low compared with private contractors. Project management as a process however, is well understood.

4.11 The scope of work now associated with the cylinders is in our opinion substantially beyond the resources and capability of NRM, both in terms of plant, equipment and personnel. It is therefore necessary for the *Flying Scotsman* to be sent to an external specialist contractor for completion of the restoration works. There is a draft plan for this in place which involves a work programme of 60 weeks including commissioning and testing. Programme commencement on 7th January 2013 would enable completion by April 2014. [redacted]

4.12 Following discussions with the staff of the appointed Rail Vehicle Acceptance Body, it has been accepted that our proposed way forward on the restoration work in connection with the steam cylinders of *Flying Scotsman,* is the correct way forward

4.13 The initial proposed work scope did not include any repainting of the locomotive either, from its current matt black finish. This remains the case, with no financial allowance or programme time allowed to undertake any painting built into the submission. [redacted] a delivery timescale expected to be of the order of fourteen days

4.14 From various reports, including the 'Meanley Report', from our discussions with experienced steam locomotive engineers with practical and theoretical knowledge of Gresley locomotives and through the study of a range of drawings and papers, it is clear that, while in private ownership, *Flying Scotsman* has been significantly modified from the original design characteristics of the LNER A3 design. Prior to NRM ownership, the locomotive has been consistently overworked, by a combination of excessive trailing loads and operating timetables that were extremely challenging. Coupled with poor maintenance, this was altogether unsustainable in the longer or even medium term, for a locomotive that is part of the preserved fleet.

4.15 We consider it essential that a total review of operational and maintenance strategy is undertaken and put in place before *Flying Scotsman* is put back in operational service. In our view, failure to do so will place considerable risk on the sustainable future service reliability of the locomotive and of course, its reputation. To this end we have incorporated in the Appendices (7&8), the fundamental parameters that should be incorporated in a revised operational approach and a 'fit for purpose' maintenance regime.

4.16 The NRM is not equipped or resourced to undertake the heavy overhaul of mainline steam locomotives of the magnitude similar to that required by *Flying Scotsman*. In our view, its facilities, equipment, engineering management and staff skill sets need considerable enhancement, including additional professional resources of project and financial management.

4.17 [redacted]

[redacted]

5.0 Project Planning and Programming

5.1 Gantt charts in Windows Project software format have been produced reflecting the results of a Critical Path Analysis (CPA) process. The CPA identifies the logical progression of all work elements to achieve the shortest overall delivery programme. The chart will enable detailed monitoring of physical progress in the remainder of the restoration programme, [redacted], the NRM Project Manager and FCP. A short form version of the programme features in Appendix 5.

5.2 [redacted] delivery programme to completion, including testing, running–in and commissioning, consists of a total of 60 weeks, resulting in the locomotive not being available for operation in 2013. Early authority to commence the work therefore, is essential if it is to be available, albeit for a limited time, in 2014

5.3 [redacted] delivery programme to the same scope runs for a total of 74 weeks and even with early authority to proceed would result in significant loss of operation to the 2014 programme. A short form version of the programme is shown in Appendix 6

6.0 Financial Estimates and Forecasts

6.1 [redacted]

6.2 [redacted]

6.3 [redacted]

6.4 The summary financial position is:

NO.	PACKAGE	OPTION 1 - [redacted]	OPTION 2 - [redacted]
	Primary Labour Costs		
1	3no.Cylinder Rectification Package	[redacted]	[redacted]
2	New 2 to 1 Stretcher Installation	[redacted]	[redacted]
3	Buffer Beam supports	[redacted]	[redacted]
4	Smoke Box Re-instatement Works	[redacted]	[redacted]
5	Air Brake Pipe work/systems	[redacted]	[redacted]
6	Cab Completion	[redacted]	[redacted]
7	Boiler Integrity Test and Associated Items	[redacted]	[redacted]
8	Motion Works Completion & Assembly	[redacted]	[redacted]
9	Ash Pan and Fire Box Completion	[redacted]	[redacted]
10	Remaining Pipe Work/Systems	[redacted]	[redacted]
11	Bogie Repairs	[redacted]	[redacted]
12	OTMR and TWPS (NRM Supply)	[redacted]	[redacted]
13	Tender Minor Works	[redacted]	[redacted]
14	Sundry Works	[redacted]	[redacted]
15	Commissioning Process	[redacted]	[redacted]
	Labour Costs Totals	[redacted]	[redacted]
	Materials Costs		
	Materials	[redacted]	[redacted]
	Materials Sub Total	[redacted]	[redacted]
	Final Labour and Material Costs Totals	[redacted]	[redacted]
	Additional project Costs		
	*NRM Admin Assistant and Contract Manager Fees	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]
	Support Coach Extras	[redacted]	[redacted]
	Project Management Fees	[redacted]	[redacted]
	[redacted]	[redacted]	[redacted]
	Section Sub Total	[redacted]	[redacted]
	Final Sub Total	[redacted]	[redacted]
	Proposed Contingencies		
	10% Materials Contingency	[redacted]	[redacted]
	10% General Labour Contingency	[redacted]	[redacted]
	Section Sub Total	[redacted]	[redacted]
	Forecast Project Costs	[redacted]	[redacted]

Current and committed expenditure at 5th December [redacted]

GRAND TOTAL [redacted]

CURRENT FINANCIAL AUTHORITY [redacted]

CURRENT FINANCIAL AUTHORITY [redacted]

ADDITIONAL FUNDING REQUIRED ABOVE AUTHORITY [redacted]

6.3 [redacted]

6.5 [redacted]

6.6 [redacted]

6.7 [redacted]

6.8 [redacted]

7.0 Conclusions

7.1 Based on the record of work done over the past seven years, the certification produced and the physical examination of the *Flying Scotsman* we agree that work packages 2 to 10 and 12 to 15 are required. Package 11 (bogie repairs) needs to be extended to include a Non Destructive Test (NDT) on the bogie frame structure. Our professional engineering judgment is that if sustainable reliability is to be achieved for the future operational performance of the locomotive, the initial proposed treatment of the middle cylinder alone is unacceptable. It is necessary therefore for the middle cylinder to be correctly installed in the locomotive main frames and for new liners to be fitted in all three cylinders, bored out to 19 inches diameter.

7.2 The scope of work now associated with the cylinders is beyond the resources and capabilities of NRM, in terms of plant, equipment and personnel. It is therefore necessary for the *Flying Scotsman* to be sent to an external specialist contractor for completion of the restoration works. There is a draft plan in place which proposes a programme of work running for 60 weeks to include testing, running-in and commissioning following completion of the restoration work.

7.3 [redacted]

7.4 [redacted]

7.5 [redacted]

7.6 If in the future the NRM is to consider undertaking the overhaul of mainline steam locomotives of the magnitude similar to that required by *Flying Scotsman*, then in our view, its facilities, equipment, engineering management and staff skill sets need considerable enhancement, including additional professional resources embracing project and financial management.

7.7 We believe that it is necessary for NRM to put in place an appropriate call off contract for a Chartered Mechanical Engineer who is knowledgeable of steam locomotive engineering practice. The current Engineering and Rail Operations Manager needs to have access to such a person when issues beyond his experience and technical knowledge arise. Similar consideration should apply to other types of diesel, electric traction owned and operated by the NRM

8.0 Recommendations

8.1 It is recommended that the Finance and Strategy Committee authorise the commencement of contract negotiations with a specialist external contractor to undertake the required work packages to complete the restoration of *Flying Scotsman* based on the scope of work identified and outlined in the documents tabled to them during this investigation, namely:

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning [redacted]

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning [redacted]

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning [redacted]

4472 *Flying Scotsman* Engineering Overhaul Completion and Commissioning / Component / Systems Repair Status Document

8.2 If a contract is awarded to an external specialist contractor NRM should reassess its internal resources and processes for engineering control, project management, financial management and contract management necessary for monitoring and reporting on the performance of the contract.

8.3 For operation of NRM steam locomotives, NRM needs to take action to have available to them a Chartered Mechanical Engineer, knowledgeable and experienced on steam locomotive engineering, who can provide professional advise to them on areas of technical expertise over and above that currently available. The requirement is unlikely to have a high frequency of demand and therefore a call off arrangement would be appropriate. Similar consideration for Professional Engineering advice needs to be given relative to other rolling stock which they wish to operate.

Appendix 1-Persons interviewed

Jonathan Newby, Chief Operating Officer SCM
Paul Kirkman, Interim Managing Director NRM
Helen Ashby, Head of Knowledge and Collections, NRM
Anna Evans, Head of Property and Project Management (North), NRM
Chris Beet, Engineering and Rail Operations Manager, NRM
Chris Chesney, Project Manager, NRM
[redacted]
Bob Meanley, Managing Director, Vintage Trains
Peter Townend, former Shedmaster Kings Cross Top Shed
Graeme Bunker, Steam Locomotive Driver and Fireman
Wayne Jones, Wayne Jones & Partners, the Vehicle Acceptance Body (VAB)
John Graham, Wayne Jones & Partners.

Telephone discussion with Keith Nicholson, Steam Locomotive Brakes System specialist

Appendix 2 Proposed Work Packages

No.	Package
1	3 No Cylinder Rectification Package
2	New 2 to 1 Stretcher Installation
3	Buffer Beam Supports
4	Smoke Box Re-instatement Works
5	Air Brake Pipe Work/Systems
6	Cab Completion
7	Boiler Integrity Test and Associated Items
8	Motion Works, Completion & Assembly
9	Ash Pan and Fire Box Completion
10	Remaining Pipe Work/Systems
11	Bogie Repairs
12	OTMR & TPWS (NRM Supply)
13	Tender Minor Works
14	Sundry Works
15	Commissioning Process

Appendix 3 Steam Locomotive Engineering Principles

1 As a means of power production, the conventional steam locomotive is unusual, in that power is transmitted from the cylinders to the driving axles, of which there will be two or more - three in the case of *Flying Scotsman*. The centres of the driving axles are partly fixed but subject to considerable movement in relation to each other. Power is transmitted to and between the axles by rigid couplings which are subject to rotating and alternating compressive and tensional forces. These movements, caused by the locomotive itself, both direct and induced along with others brought about by irregularities in the track, under the control of the locomotive's springs affect the dimensions between the axle centres. If there are any errors in a locomotive when the component parts mentioned are assembled at overhaul, while it is possible they may cancel themselves out, equally they might add to each other, allowing stresses to build up over and above the design parameters of particular parts of the locomotive.

2 It follows therefore, that the higher the original accuracy, the lower will be the maximum stresses with the possibility of reducing the tolerances in the working parts to a minimum. This in itself will reduce the hammering effect in bearings and the rate at which wear takes place. Having already made the effort and expenditure to ensure that the wheels and axles meet these criteria, it is our view that it is essential that the front end of the locomotive comprising the cylinders and valves are overhauled to the same standards. This is one of the reasons why we are making the recommendations regarding removal of the cylinders, followed by any remedial action to establish standards compatible with the work that has already been undertaken to the rest of the locomotive.

Appendix 4 - Main Steam Cylinder Issues

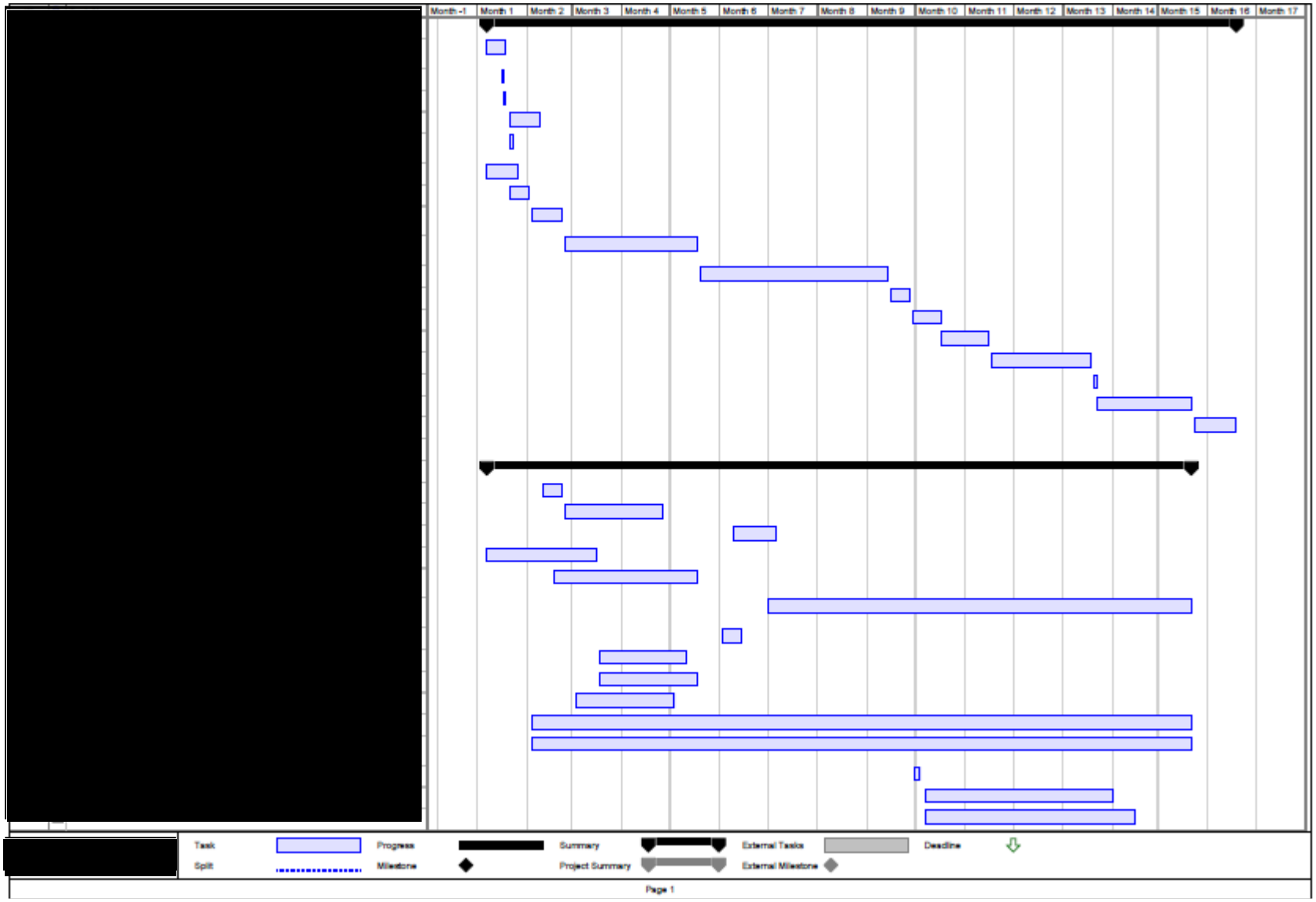
1 Since the engine was acquired from BR the middle and right-hand cylinders have been changed; in both cases with second-hand ones from other locomotives. The decision to change the cylinders was based on the replacements being in better condition. The middle cylinder was replaced at a June 1999 overhaul, the right-hand one while the engine has been on the 'Heavy General' overhaul at York. Currently the middle cylinder bore is misaligned longitudinally in relation to the engine frames. While the miss alignment is relatively small at the cylinder, when transmitted the distance to the journal of the crank-axle on the intermediate set of coupled wheels, it is around a quarter of an inch out of line at the Connecting Rod Big End. While the engine must have been used in this condition, it would have affected its smooth running. The big-ends survival is probably due to wear in other associated components, axle boxes, spring gear, the little end of the connecting rod, along with side play in the big end itself. As all this wear has now been corrected and the relevant parts of the engine restored to as drawing condition; if the engine is allowed to run in this condition distress of the big-end will follow, which could be catastrophic

2 The original NRM plan was to have the middle cylinder bored out with specialist equipment capable of correcting the error. The correct engineering approach is to remove the cylinder, establish the exact reason why it is misaligned and make the necessary repairs. There is evidence of a thin shim having been inserted between the cylinder and the right-hand frame plate and there is a slight joggle in the left-hand frame plate between the cylinder and the leading coupled wheelset. To remove the middle cylinder, the outside ones have to be removed too. Two other issues are relevant; firstly there is a variation of 0.44 inches on the length the bores on the three cylinders and care will need to be taken when the engine is reassembled to ensure that sufficient clearance exists on each cylinder between the piston head at the end of its stroke and the end of the cylinders. The second issue is the middle cylinder being slightly out of alignment vertically and whilst it is not entirely clear what effect this has had on the overall problems at the front end of the locomotive, realigning the cylinders will allow it to be addressed and corrected. The left-hand and middle cylinders have a nominal diameter of 20 inches while the right-hand one is 19½ inches. When built the engine had 20x26 inch diameter cylinders and a boiler pressure of 180lb. A new boiler with a higher degree of superheat and a working pressure of 220lb was later fitted. It was then discovered that the cylinder horsepower exceeded the boiler output, so the cylinders were reduced in diameter to 19inches. The locomotive now has a boiler with a working pressure of 220lb, so the cylinder diameter should be 19inches. When the cylinders are removed they will be fitted with new liners and restored to a diameter of 19inches, which with the 220lb boiler pressure puts the engine back to its design characteristics.

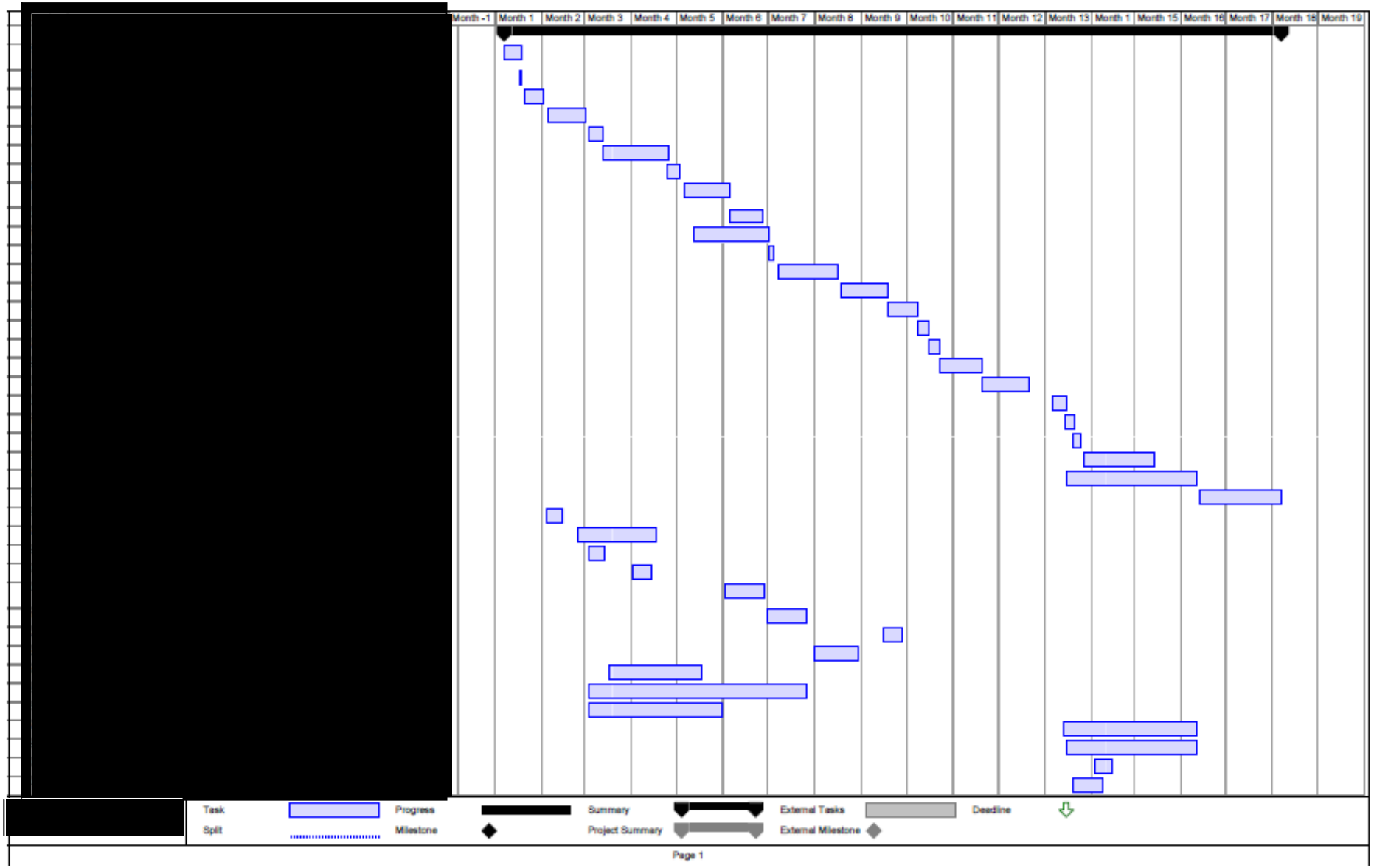
3 In 1978 a boiler with a working pressure of 250lb was fitted and the engine was operated with that boiler until it was taken out of service for its current repair. For the period since then, it would appear that the engine has been running with 20 inch diameter cylinders. No Gresley three-cylinder engine was designed to operate with 20 inch diameter cylinders and a boiler with a working pressure of 250lb. This might partly explain why the engine has been found to be in such a poor condition.

4 The tractive effort of a locomotive is increased by approximately 33%, by enlarging 19 inch cylinders and a 220lb boiler pressure to 20 inch cylinders and a 250lb boiler pressure

Appendix 5 [redacted]



Appendix 6 [redacted]



Appendix 7 Operations Strategy

Introduction

Flying Scotsman is approaching its 90th year and has been in private ownership since 1962. In both public and private ownership it has been recognised as an iconic steam locomotive and was bought by NRM for 'The Nation' in 2004. It is now one of the principal steam locomotives in the NRM preserved fleet of steam locomotives and there is likely to be a public demand for *Flying Scotsman* to remain operational for some years into the future.

The engineering condition of the locomotive has been critically examined at various stages during the period of the current major overhaul. From a number of earlier reports, particularly the 'Meanley Report' and from our own observations there is little doubt that *Flying Scotsman* was in very poor condition when purchased by NRM. It had been consistently overworked for a number of years by a combination of excessive trailing loads and operating timetables that were extremely challenging. Coupled with poor maintenance this was altogether unsustainable for a locomotive that is part of the preserved fleet.

When the current major overhaul is complete in the early spring of 2014, it is essential that a revised operations strategy is put in place before the commercial operations programme is agreed and before the *Flying Scotsman* enters operational service. It is considered that by such actions it will enable sustainable availability and reliability of the locomotive over a longer term timescale.

Operational Utilisation

There are a number of operational aspects which can and will have a deleterious impact on longer term operational usage of steam locomotives. The principal of these are the annual mileage run- this itself divides into numbers of trips and the mileage run on each trip; the maximum hauled load; the way that the locomotive is driven and fired particularly on mainline charter services running at up to 75mph. There are other matters however including operation on preserved railways where continuous stopping and starting on twisting lines at 'Gala' type events has an undesirable and disproportionate impact on wear and tear of the locomotive.

With regard annual mainline usage we would endorse the comments in the 'Meanley Report' to maximise annual mileage to no more than 6,500 to 7,000 miles, with each trip being limited to between 250 and 350 miles. This builds on the experience of other prudent owners and operators of similar steam locomotives who wish to achieve a medium to long term usage of a preservation type asset. As a consequence between 22 and 26 trips per year would be permissible and such an approach will create an appropriate balance between service running for public pleasure and reasonable wear and tear on locomotive moving parts and/or boiler equipment.

It is proposed that a load limit is set for each of the routes that the locomotive is likely to work over. This can be reviewed in light of operational experience and revised going forward, but there should also be a degree of judgement applied in terms of the sectional running times asked of the locomotive. Similarly, short climbs have a different effect on the boiler and firebox than a long climb with sustained high output required for 30 minutes or more. Each train should be viewed on its merits, but it is correct to have a base to start from. An example of some likely core routes is shown below with the potential loadings. Note that this is not about what the locomotive can haul on the route, but about what it can haul on likely timings and without over working the engine. Tare tonnage including the support coach is shown; vehicle numbers are exclusive of the support coach and shown in brackets.

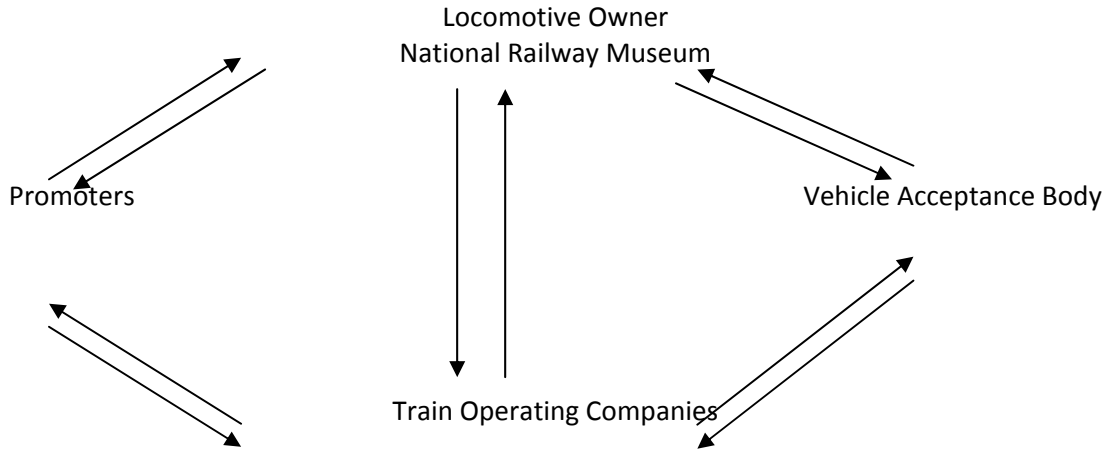
Route	Suggested Load	Comments
York to	420t (11)	No steep gradients or long climbs

Scarborough		
York to Settle and Carlisle	385t (10)	Heavy climbing in each direction
Newcastle to Carlisle	385t (10)	Heavy climbs in each direction
York to Newcastle	420t (11)	Fairly flat route with limited gradients
London to York	385t (10)	Sustained long climbs in each direction
Newcastle to Edinburgh	385t (10)	Sustained long climbs in each direction
London to Bath (via Swindon)	420t (11`)	No prolonged or heavy climbing
London to Chester	385t (10)	Sustained long climbs in each direction
Bristol to Paignton	385t (10)	Some stiff and challenging gradients

In due course a full loads book should be produced and shared with all stakeholders to ensure a robust planning process for the locomotive.

Relationships for Mainline Operations of Steam Locomotives

The main line steam industry is a complicated environment with four main constituent parts, and several interactions between the parties. The key relationships are;



When considering operating on the main line it is important to factor in these interactions as without one of the parties above, NRM cannot operate.

Relationships with Promoters

The National Railway Museum has undertaken a process to identify partners to help it promote *Flying Scotsman* to the nation. To ensure robust planning the NRM needs to offer to the companies a locomotive in a 'ready to run' condition, with full certification, insurance, staff, etc. NRM should seek to agree particulars with the train operating company and then advise the promoters of this situation, recognising that they plan their tours many months and in some case years, in advance. This is of benefit to the NRM as it allows for robust planning and minimal last minute resource requirements.

Critical to the above process is planned maintenance periods. The NRM should on receipt of the draft programmes look at the implications for maintenance including but not limited to washouts, annual exams, tyre turning, etc. As well as an agreed programme of tours the diary should clearly show when the locomotive is on maintenance and therefore unavailable. Only in the most extreme of circumstances should the locomotive be turned out for traffic and maintenance compromised.

The promoters should be advised of any and all operating restrictions, planning assumptions (such as load limits), depot facilities that are acceptable and so forth and issue these as early as possible. Any diarised commitments for NRM events, pre-agreed visits to preserved lines should be communicated.

Relationships with Train Operating Companies (TOCs)

The train operator is perhaps the most critical relationship in the operation of *Flying Scotsman* as once off depot the train operator is responsible for the locomotive. It is under their operational procedures, train crew, licence and insurance and because of this there is a need to be proactive at all times. It is not sufficient to find the locomotive finished and then engage the TOCs.

NRM should limit the number of organisations that operate the locomotive to an absolute minimum; two is proposed and both of these must have rules and regulations in place to ensure that strong discipline is implemented in treating *Flying Scotsman* in a professional manner at all times.

It is also essential that when the locomotive is in use on the national network a member of the NRM staff should be present at all times to ensure it is properly maintained and driven. Maximum speed should be no more than 75 mph and mainline route point to point timings such that the locomotive does not need to be driven at anywhere near its maximum potential.

Long term reliability of the firebox has many dependencies including professional driving and firing techniques. A further key aspect relates to ensuring a slow build up when raising steam from cold- typically this should be an operation of 24hours duration. Similarly when going from service operation to the cold condition this needs to be carefully managed over a reasonable period of time. The objective of these two activities is to minimise the heat induced stresses that arise in the firebox when significant temperature differentials occur between hot and cold states. There is also evidence that some types of imported coal generate substantial ‘clinker’ resulting in undesirable ‘hot’ spots in the firebox- in BR days Welsh coal was considered to be the best product for effective heat generation.

For the successful promotion of the locomotive it is critical before operations begin that the relevant agreements, audits and methods of working are reached between the operator and the NRM.

The following are areas that are critical to that process;

- Audit of Maintenance and Overhaul Policy
- Review of all insurance certification
- Competency Matrix for Operational, Engineering and Support Crew staff
- Inspection of the locomotive

The above are routine and apply to all engines, and although not exhaustive are the areas that are recommended to be prioritised.

When working with operators it best to have an open policy and from time to time when defects occur or a failure is not avoided, the operator should be kept abreast of the causes and remedial actions.

With the significant investment in the locomotive it is important that it is treated well, and the train-crews who are involved have a key role to play. It is not unreasonable for the NRM to insist that train crew who operate the locomotive are familiar with LNER wide firebox locomotives and their particular idiosyncrasies. Both the current TOCs used by NRM have many high quality staff who have worked on the various A4 locomotives and on the new A1 locomotive in recent times, and some who have experience of *Flying Scotsman* in previous years meaning that the locomotive should be well cared for when out on the mainline. It is also essential that when the locomotive is in use on the national network a member of the NRM staff should be present at all times to ensure it is properly maintained and driven

A final element where TOCs have a role to play is that they are the liaison with Network Rail during the planning process. Given the suggested parameters set above it is crucial that these are not eroded by a diesel being added to the trailing load for operational convenience or to heat the train, without a suitable reduction in coaches. Depot facilities should be agreed so that the locomotive is always stabled at a place where the relevant servicing and/or maintenance can be undertaken.

Relationship with the appointed Vehicle Acceptance Body

The National Railway Museum has appointed a VAB well recognised for its knowledge of steam locomotives. In its dealing with the VAB there is always a point at which the VAB will have to decline to offer advice, but within the norms, an open, no surprises approach is best adopted so that throughout the operating life of the locomotive certification is always up to date, enabling any modifications to be properly thought through and signed off, and all maintenance is carried out to the relevant standard and at the right frequency.

Other key areas to address given the complexity of parties involved with any locomotive are;

- Engineering Acceptance Certificate is not operator specific
- Derogations have been submitted in good time for the locomotive and support coach
- TOCs are involved at the right time in the process to ensure their concerns have been recognised.

Historically there has been a tendency for VAB's only to become involved at the end of a project, which can lead to delay and additional costs. Early involvement and regular interaction can avoid these problems.

Operations on Preserved Lines

Locomotives such as *Flying Scotsman* were not built for preserved line duty and do not benefit from constant stopping and starting on curvaceous lines. The operation of *Flying Scotsman* on preserved railways should be limited to between two and three per year and only to those locations which are physically connected to the main railway system. The frame structure on A3 locomotives is known to have experienced minor distortion problems in earlier years, requiring some reinforcing to be undertaken by the welding of additional side plates To avoid undue stresses occurring in the main frames of *Flying Scotsman,* transportation by road haulage should not be considered as an acceptable means of movement except in emergency situations. The 'Meanly' report states that "several leading locomotive owners and operators in the main line market who will not countenance the loan of their locomotives to private railways and other such events, and they are succeeding in demonstrating the wisdom of such an approach".

When running at low speeds the normal lubrication processes are not always as effective on the internal components. This is particularly relevant to valves and cylinders but can also affect other parts. Again, it is about balance and having the locomotive doing a reasonable amount of work per day, not high mileages which cause more wear and tear than the hire fees justify.

Train crew are very unlikely to be familiar with the locomotive and there is a risk to damage to the firebox if the fireman is not conversant with a wide box as fitted. Cold air will enter the firebox and cause damage and excessive wear and tear to the components. Similarly, if not familiar with the air braking fitted to *Flying Scotsman*, or potentially unfamiliar with air braking at all, there is a risk of poor braking technique leading to exposure of the crown sheet of the firebox. This is not only dangerous but could cause an expensive repair to be required.

All these things can be managed but it is important that mitigations are put in place. It is also important to note that preserved railways do not always attract such strong volunteer turnout so it

may be that an almost entirely paid staff compliment is needed to support the locomotive and ensure it is well looked after, maintained well and turned out in good external condition for the public to enjoy.

As in main line operations care is necessary to achieve long term reliability of the firebox. Professional driving and firing techniques are important, however a further key aspect relates to ensuring a slow build up when raising steam from cold- typically this should be an operation of 24hours duration. Similarly when going from service operation to the cold condition this needs to be carefully managed over a reasonable period of time. The objective of these two activities is to minimise the heat induced stresses that arise in the firebox when significant temperature differentials occur between hot and cold states. There is also evidence that some types of imported coal generate substantial 'clinker' resulting in undesirable 'hot' spots in the firebox- in BR days Welsh coal was considered to be the best product available for effective heat generation.

Water and coal are provided by the railway, and the data for this needs to be provided by the railway so that planning of water treatment can be done. Water varies around the country and can have a significant effect on the boiler so knowledge of the local conditions and suitable treatment with approved chemicals is required. Similarly coal that causes pitting of tube ends, or is so hot it damages fire-bars is not to be recommended. Although it is not always possible to source the perfect coal for any engine, cheap coals should be avoided to prolong boiler life. If there is any doubt then chemical composition should be provided by the preserved railway so as to alleviate any concerns.

When on loan on preserved railways, a member of the NRM staff should be present at all times when the locomotive is in use to ensure it is properly maintained and driven. Special attention should be given to preparation and disposal duties as well as driving and firing techniques. In selecting those railways the engine might be used on, consideration should be given to gradients and track curvature, such that the engine is not required to work on lines with infrastructure constraints more taxing that those it was designed to cater for, such as lines with sharp curves

To ensure *Flying Scotsman* is not overworked on these visits it is recommended that the NRM restricts the time away from the shed to less than 12 hours or makes an additional charge to the railway so that more staff can be provided to look after the locomotive.

Finally; if the locomotive is booked for photo charters then specific arrangements should be put in place to ensure that the locomotive is not driven excessively to provide a spectacle for the photographers. The fees earned from a day of photography will not pay for repairs needed because the boiler has been over stressed by harsh driving.

NRM Operational and Engineering Support Resources

The resources required to operate a locomotive on the main line in the 21st Century have moved forward from when privately owned steam locomotives first ran on the national network in the 1970s. It is important that all personnel are properly trained, qualified and certified for the duties they are undertaking.

The first instance is to review how many team leaders are needed to manage the work required. Traditionally referred to as a Responsible Officer (or RO) they are a senior person working for the NRM (paid and volunteer) and who has experience of running on the main line. The skills needed for such a person would be as follows;

- Strong character familiar with management responsibility
- Capable of making decisions and communicating well
- Understands planning requirements for steam operation
- Has good working knowledge of steam locomotives on the network
- Has an operations or engineering background, or both

- Knows the locomotive (or the type) in question well
- Understands the importance of a well turned out locomotive
- Is medically fit and in possession of a valid Personal Track Safety (PTS) card

The above is not exhaustive but does give an idea of the individual required, Are they capable of taking the decision to stop the locomotive when there is a risk of damage, or to intervene if it is not driven or fired as best suits the loco? The key people have to be able to make the correct decision in partnership with the TOC and promoter, but also to ensure no damage to the locomotive or the NRM's reputation. Training in this role is available from some sources and should be considered.

It is also critical that the locomotive goes out with an engineer capable of looking after all its systems. This person should be deemed competent in the following areas;

- Boiler management and all associated systems (blower, injectors, etc)
- Competent on the air braking system to identify faults and carry out repairs
- Competent on OTMR, TPWS and GSMR systems
- Understands white metal bearings and the peculiarities
- Capable of preparing the locomotive fully for a Fitness to Run Exam
- Competent in operation of water treatment system
- Able to instruct and supervise others

To enable competency to be demonstrated it is suggested that a full competency matrix be put in place showing the individuals, the skills they have and when they were assessed. This should be backed up by documentation showing training given, how the assessment was undertaken and who by. This approach has become the norm in the main line steam movement and the NRM should seek to adopt best practice.

As with most engines a team of volunteers are often employed to help with the operation and preparation of the locomotive. This is not to be discouraged and such individuals can be accommodated within a competency matrix system. A key to ensure successful operations on the main line is that the owner's representative, the person who rides on the locomotive with the train crew, is of sufficient capability and experience to fulfil the role. When putting the above team together consideration should be given to a full time engineer to provide the continuity between the operational activities and the planned maintenance such as wash outs, examinations and repairs. This link is particularly beneficial when working on preserved lines where the engineer can ensure that the locomotive is maintained in line with agreements with the VAB and TOCs.

Next Steps

The group responsible for the running of *Flying Scotsman* and its maintenance need to set out with a clear set of objectives and standards to ensure a clean, highly reliable locomotive is presented on each trip. This will create a great impression on all who see and travel behind *Flying Scotsman.*
The following next steps are proposed to help achieve these endeavours;

- Briefing of NRM and adoption/modification of proposals
- Meetings with all key stakeholders to identify their requirements
- Construction of a loads table for all proposed routes in the UK
- Review of current personnel and written procedures
- Construction of Competency Matrix and supporting systems
- Review of proposed personnel and identification of competency gaps and training needs

Appendix 8 Maintenance Strategy

1 The BR Maintenance Approach for Steam Locomotives

1.1 British Railways had a very comprehensive system for the maintenance of steam locomotives developed over many years. On its formation in 1948 it inherited over 20,000 steam locomotives of more than 400 types and with different maintenance systems used by each of the four pre-nationalised Companies. It was decided the entire fleet should be maintained on the London Midland & Scottish Railway (LMS) system, officially known as *Locomotive Maintenance & Mechanical Efficiency*, though usually as the *X Scheme of Examination & Repair* and colloquially, as the *MP11*.

1.2 The methodology was for locomotives to be stopped at predetermined periods and with the exception of any serious defects developing, they could be kept in steam and utilized between the times when they were stopped, with the minimum of attention apart from routine servicing. The day they were stopped was known as X day, the periodicity dependent on the type of work they were used on. Locomotives predominantly working express passenger trains had X day examinations at between six and eight days, other locomotives on passenger trains 12-16 days, locomotives used on freight trains 12-16 days and shunting locomotives 24-32 days. The X day examination consisted of a detailed examination of all parts of the locomotive both when in steam and when cold, with any repairs arising being dealt with. Attention would also be given to any defects reported by drivers including any minor ones that might have been deferred during the period since the last X day. For this examination the locomotive had to be placed over an inspection pit.

1.3 Two basic principals applied for the maintenance beyond the X day; moving parts were given attention on a mileage run basis and stationary parts attention on a time lapsed basis. Those parts on a mileage based system were attended to at periodicities varying from 10,000-12,000 to 40,000-48,000 miles, while for those items on a time basis, the period varied between 3-5 weeks and 7-9 weeks. However, any of these examinations that fell due, were always timed to coincide with the engine being stopped for its X day examination. It follows then, that an engine stopped for its X day exam, might also have at the same time, a mileage or a time based examination, or both. In such cases it might of course, be stopped for longer than a day. Boiler washouts would also be undertaken on X days if they were due, the periodicity depending on local practice connected with the quality of the water. In some cases it was necessary to stop engines between X days specifically for a boiler washout - those on periodicities longer than the six to eight days for example, if in fact it was necessary in view of the water quality, to wash the boilers out at a weekly interval. It was however, the local practice at most sheds for an X day examination to be undertaken whenever the boiler was washed out, whether one was due or not. Whenever a boiler was opened up for a washout, the Boilersmith would make as thorough an examination as possible through all the openings.

1.4 When engines arrived on the shed for an X day and any other examinations, they would be given a thorough examination while still in steam, by an experienced Examining Fitter who would test all the equipment including the pipe joints and other fittings in the smokebox. For this test he would employ a mate to apply the brake and open the regulator slightly, using a lighted flare on the end of a long rod, for the source of any steam leaks could be established. The engines would be properly disposed of, including cleaning the tubes, large and small, with a steam lance. After the engine had been stabled in the shed and placed over a pit, another experienced examining fitter would make a further detailed examination, in both cases noting any repairs needed. Once the engine had cooled down, the firebox would be cleaned, a job that consisted of removing all debris from the firebox plates, on top of the brick arch and any bird's nests from the tube ends. This would allow a Boilersmith to make his examination of the firebox which would include a hammer test of all the stays, along with the condition of the grate, ashpan and brick arch.

1.5 The lower mileage examinations consisted of a visual inspection of the motion and valve gear parts after cleaning them such that any defects might be observed. At higher mileage the connecting rods, coupling rods, crossheads, pistons and valves would be removed for attention. All the bushes

would be removed, the white metal renewed and the bushes machined to fit the journals. The crossheads would similarly be re-metalled, while the cylinders and valve chests along with the blast pipe would be cleaned of all carbon deposits. Piston and valve rings would be renewed and any other defects found in the valve gear parts would be given attention. Great care would be devoted to the lubrication, with all the felt pads and wick trimmings renewed. Mechanical lubricators would have their delivery pipes disconnected at their delivery points, the lubricator then being operated by hand to ensure that the oil was being delivered correctly to the moving parts.

1.6 The non-moving items would be examined, for example gauge glasses renewed, water and steam passages rodded through, packing renewed in the operating valves. The vacuum ejector cones would be cleaned, boiler feed clacks dismantled and the seats and valves examined, re-cutting and machining as required and a host of other jobs.

1.7 In addition to the forgoing, all engines used on passenger or long distance freight trains, would have a daily examination prior to taking up work with the engine over an inspection pit. The Examining Fitter would make a visual and hammer test examination for any loose, damaged or missing parts with particular reference to all split pins, cotters and other methods of security.

2 The Recommended Future Maintenance Approach for Operational NRM Steam Locomotives

2.1 The repairs undertaken on the boiler of the locomotive and subsequent testing will allow a certificate to be issued when it returns to service, for a period of 10 years before its next heavy repair. Therefore, provided it is looked after properly, water treatment undertaken and no unexpected faults occur it would not need to be removed from the locomotive during that period. This 10 year periodicity between heavy overhauls is the standard practice that has been developed for steam locomotive boilers in recent times. Any repairs that may become necessary should be capable of being undertaken with the boiler still on the locomotive. It is recommended that the locomotive be limited to around 70,000 miles during the 10 year period at an average, say 600 a month, with intermediate repairs at around 22,500 mile periods. This would include valve, piston and motion repairs and attention to axle boxes and journals on locomotive and tender as appropriate.

2.2 For *Flying Scotsman*, or indeed any other steam locomotive the NRM operates, usage will be lower and much more spasmodic than any former BR operation. However, the principles outlined above should be adopted, adjusted to suit the number of days the engine is used and the mileage accumulated. It is vitally important that preparation and disposal duties are correctly and diligently undertaken. On preparation special attention should be given to all the lubrication points, wick trimmings, restrictors etc, with the correct grade of oil used which must be of a high specification. On disposal the firebox, ashpan and smokebox should be thoroughly cleaned as best they can and then given more attention when the engine has cooled down. A detailed examination of all the lubrication points should be made occasionally, to ensure that the wick trimming and restrictors are adjusted correctly so that each and every part get sufficient oil/grease. When raising steam on the locomotive, at least 18-20 hours should be allowed between lighting the fire and reaching maximum steam pressure. Yet another essential aspect is chemical treatment of the boiler feed water, the exact content of which will depend on a detailed analysis of the water wherever the engine is working.

2.3 The current NRM Maintenance Plan for its steam locomotives, Issue 1.2 dated April 2007 appears to be comprehensive and generally in accordance with principles of the former BR system. In is far more stringent in many areas and scope exists to possibly reduce some of the requirements, for example where attention is specified at time intervals irrespective of how many days the engine has actually been in use. Conversely, some items might benefit from a lesser period if the criteria were miles run rather than a periodicity that takes no account of this. There are one or two issues that need to be addressed that are specific to *Flying Scotsman* and these need to be embodied in the plan. The current Engineering and Rail Operations Manager is aware of these shortcomings and has action planned to address them.

2.4 As recommended in the Meanley Report a key factor affecting reliability and repairs is not to entrust the care and maintenance of *Flying Scotsman* to other organisations. To undertake the servicing and maintenance of the locomotive the NRM needs to develop a dedicated, knowledgeable and experienced team, whether volunteers, full-time staff or elements of both. The view within the railway preservation movement is that if the locomotive is going to be used for up to 10 days a year, volunteers can probably cope with the bulk of the workload, provided there is experienced full-time staff to supervise the work. However, if the workload of the locomotive is greater than 10 days a year, a base-load full-time team will be required, bearing in mind that at different times, it could be operating all over the country. It is recommended that all the examinations over and above the daily servicing, preparation and disposal, should be undertaken at York. This will ensure that the work is carried out in well equipped facilities, adequate for the level of work required. It will also enable the work to be undertaken at the home base of the support staff, with competent supervision and where high class quality control can be established.

3 Future Maintenance Policy for Heavy Overhauls of Steam Locomotives

3.1 The scope of work entailed in heavy overhauls is extremely large and requires a substantial range of skilled resources, a wide range of plant and machinery, a deep knowledge of the logistics of overhaul processes and the engineering standards that must be followed. Currently NRM does not meet these criteria and they are currently available at only a small number of specialised private companies, though others may develop over the next few years as more and more of the preserved steam locomotives require heavy overhaul attention

3.2 For the heavier work, after the 70,000 miles and 10 years or thereabouts, if it is decided to continue operating the locomotive, then it will need to be taken to an adequately equipped repair facility with equipment, knowledge and experience in undertaking the heavy overhaul of steam locomotives.

3.3 For any future major overhaul of an NRM Steam Locomotive it is recommended that a more structured approach is introduced to prevent a repetition of the situation that has developed with *Flying Scotsman* during its current overhaul. A restricted contract should be let to partly dismantle the locomotive, such that a detailed and accurate examination and assessment can be made of exactly what attention is required and at what cost and time frame. A decision can then be made based on the information gathered, such that the costs and time scales of the overhaul can be established with a minimum of risk in respect of both the cost and time to undertake the necessary work.

3.2 If in the future the NRM wishes to consider undertaking the overhaul of mainline steam locomotives of the magnitude similar to that required by *Flying Scotsman*, then in our view, its facilities, equipment, engineering, project and financial management, along with the staff skill sets need considerable enhancement. Practices and procedures used throughout much of the preserved steam locomotive industry functions around a number of preserved railways being equipped with their workshops to undertake specific functions. For example, a workshop in Devon specialises in wheelset repairs while another in Bridgnorth does likewise for boilers. The result of this is that an enormous amount of sub-contracting takes place such that cost, engineering change and quality are difficult to control. While this appears to reasonably serve its purpose in an enthusiast market, one has to question its integrity for a national organisation like the NRM. A few companies, , have more wide ranging facilities enabling them to undertake much of the work with their own staff and facilities. Unless the NRM invests in enhanced facilities and equipment, develops procedures and controls in accordance with best engineering and management practices, it is recommended that in the future, NRM owned locomotives in need of heavy overhauls are placed with contractors like those mentioned above, or others with similar facilities.