The Model Deltic Locomotive at Riverside Museum

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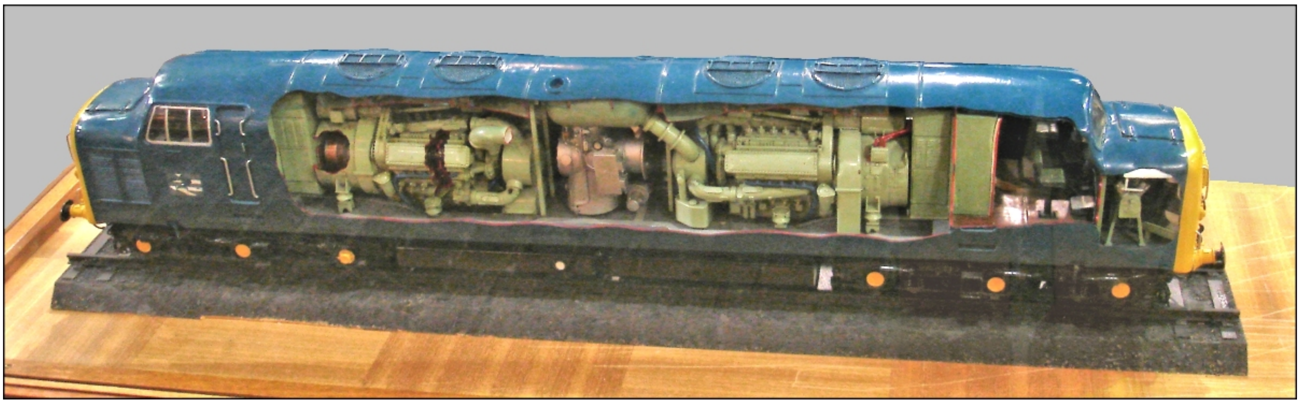
1.0 Introduction. Glasgow Museums have in their collection a number of model locomotives including examples of steam, diesel and electric locomotives. This Research Technical Note describes some of the features of just one of these models; the British Railways, Class 55, diesel-electric, *'Deltic'* locomotive *Royal Scots Grey* currently on display at Glasgow's Riverside Museum of Transport and Travel.



This model (I.D. No. T.1998.9.f) has a 6cm rail gauge (approx. 1/24 scale) and is particularly interesting as one side is sectioned to show the internal components including the power plant, heating boiler, and drivers cab. This makes the model useful in describing the layout and working of what was the most powerful single diesel-electric locomotive type when they were introduced into service in the early 1960's. Deltic locomotives were never numerous; only 33 locomotives were ever built: 1 - *'Deltic*' prototype, 22 - *'Deltic*' Class 55's and 10 - *'Baby Deltic*' Class 23's.

2.0 The Class 55 Diesel-Electric Locomotive. There are many books on the *'Deltic*' locomotive, see references 1 to 5, and for general detailed information on diesel traction locomotives reference 6 should be consulted. There is also information on the Internet, references 7, 8 and 19.

The prototype *'Deltic*' locomotive was built by the English Electric Company at their Dick, Kerr works at Preston in 1955. It was designated DP1, but being powered by two 18-cylinder Napier Deltic engines, it was to be forever known as the *'Deltic*' locomotive. The styling was reminiscent of American locomotives and the wheel arrangement was a Co – Co configuration; where the fabricated steel bogie at each end of the locomotive has three powered axles and each axle has its own traction motor(1). Structurally there was nothing unusual; there was a substantial fabricated steel oil-tight underframe with a lowered middle section. The superstructure framework was supported on the underframe. The superstructure (bodywork) comprised of rolled steel sections and steel body panels attached by welding, ref. 5 & 19. Fuel and water tanks were mounted beneath the underframe. To save weight, light alloy was used for several components including: roof sections, doors, louvres, treadplates, conduits, ducting and piping, ref. 5.

As a result of the success of the prototype, British Railways (BR) placed an order for 22 similar locomotives that became their Type 5, Class 55. The 22 locomotives cost £3,410,00, i.e. £155,000 each, ref. 5, (though reference 2 quotes £200,000 apiece). Although similar to the prototype, British Railways did demand modifications to suit their requirements, including: a change to the loading gauge, a result of service experience or to facilitate maintenance/manufacture requirements. There was also a requirement to negotiate a minimum 4-chain (264' radius) curve. Crew facilities included a breakfast cooker and a toilet. These issues are listed and discussed by Webb in reference 5. One annoying issue was high noise levels. This was anticipated by English Electric who had incorporated sound-proofing into the design of the locomotives. However British Railways considered that cab noise levels were unacceptable and several modifications were incorporated that eventually brought the noise range down to 83 – 102 dBA with all doors and windows closed, ref. 5.

All of these Class 55 *'Deltic*' locomotives were built by English Electric at their Vulcan Foundry, Newton-le-Willows works(2). They were introduced into service during 1961-62 and served on the East Coast Main Line between London King's Cross and Edinburgh, replacing the 100mph Gresley A4 Pacific steam locomotives. They also pulled the *'Flying Scotsman'* train. In the 1970's with the introduction of the High Speed Train (Class 43, InterCity 125) the Class 55's were moved onto secondary services; 1981 saw the last Class 55 in service, ref. 7.

They were originally numbered D9000 to D9021, but in the 1970's, with the introduction of the TOPS computer system[3], they were re-numbered 55001 to 55022. The model we have on display is number 55022 (originally D9000) the *Royal Scots Grey*. This locomotive is one of six that have been preserved and the '*Royal Scots Grey*' is still running, ref. 7.

3.0 The Main Layout. The main layout of the locomotive internal components including the power plant, heating boiler and the drivers cab can be seen in the photographs below. Plans and Sections of the locomotive can be found in references 1, 2 and 5.

3.1 The Power Plant. The Class 55 locomotive was powered by two 18-cylinder Napier Deltic engines. These engines were designed and built by D. Napier & Son Limited of Liverpool and Acton. A very brief history of this company is given in **Appendix 1**.

The origin of the Deltic engine lies with the Royal Navy requirements for a high-power, lightweight, diesel engine for motor torpedo boats. A very brief history of the development and working of the Napier Deltic engine is given in **Appendix 2**. The rail traction engine used in the Class 55 locomotives was a de-rated version (type D18-25B) of the engine to give a long life to drive an electrical main DC generator. Each engine developed 1650 bhp at 1500 rpm and used an engine driven mechanical blower for scavenging. Each main generator supplied a maximum of 660V, ref. 19, and were connected in series to supply 1320V max. The locomotive could operate, at reduced speed, with one engine out of action. The engines were started by using the main generators as a motor. Current to the generators was supplied from batteries along each side of the locomotive bodywork. The batteries were charged from the 110V auxiliary generators driven by the engines.

From the beginning, because of the complexity of the engine, it was intended to replace the engines at the end of the scheduled service life of 5000 hours with spare or reconditioned engines(4). To that end a total of 57 engines were available, 44 would be on the locomotives with 13 engines under overhaul or spares, ref. 5.

The engines have no flywheel and have a low inertia and hence a tendency to accelerate rapidly if the load was decreased for any reason. Control of the engine required the use of a hydraulic governor with a servo system. The governor chosen for the Class 55 locomotive was an ‘Ardleigh Engineering Ltd.’ design; now part of ‘Regulateurs Europa’. Cooling of the engine cooling water and engine lubricating and piston cooling oil was by radiator fans in the roof space above the engines. The drive for the fans being taken from the engine phasing gearbox.

3.2 Train Heating Boiler. The train heating boiler was between the two engines. The design was a Spanner Mark II steam generator and supplied steam for heating the train compartments. Water for this boiler was contained in tanks beneath the locomotive underframe and behind the fuel tanks. There was also a pneumatic operated water scoop designed for picking-up the water from troughs at high speed(8). The Spanner Mark II steam generator brought a plague of troubles; too numerous to detail here. Eventually the train heating was supplied electrically by taking current from the main generators, ref. 5 & 19.

3.3 The Drivers Cab. There were two drivers cabs, one at each end of the locomotive. It was normal to operate with a driver (on left hand seat) and an assistant. There was no provision for a nose-end gangway to the train; for non-stop working the relief crew had to ride in the trailing cab. Details of the driver controls are given in reference 1. The model shows some details of the controls and equipment in No. 2 cab (the one with the crew toilet in the compartment nose). The nose compartment also contained equipment essential to the running and safety of the locomotive and train. This equipment included:

- CO_2 cylinders; they were a BR requirement for their fire fighting regulations.
- Air Compressors; required for the locomotive air breaking system.
- Vacuum Exhausters; required for the train vacuum breaking system(9).
- Traction Motor Blowers; required for cooling the traction motors.

4.0 The *'Baby Deltic'* Class 23 locomotive. Ten Class 23 locomotives were introduced in 1959 intended for working trains around London. They were powered by one 9-cylinder Deltic engine with turbocharging, hence they were commonly known as *'Baby Deltics*'. For various reasons they were not a success, ref. 5. All were scraped by 1977. The Class 55's did benefit from the service experience of running the Class 23's and the prototype *'Deltic*'.

4.1 Deltic look-a-likes. There were several locomotives that look like the *'Deltic'*. These include BR Classes 37, 40, 44, 45 and 46. Mechanically, these locomotives were conventional with big four-stroke diesel engines that were less powerful than the *'Deltic'* locomotive.

5.0 Summary. The Class 55 locomotives were considered a success. They provided a useful rail traction role for the best part of twenty years. In their initial role they were the only diesel-electric locomotives capable of replacing the 100mph Gresley A4 Pacific steam locomotives. As such they were driven hard with high average running speed. This inevitably led to service failures; Brian Webb discusses these failures in detail in reference 5. Some of the failures were due to the Napier Deltic engines. These were unique engines designed and built by a British company whose expertise in precision engineering went back to the early days of the industrial revolution. They were designed to give as much power as possible with as little weight as possible and as such they were a complex piece of equipment; no other diesel engine could replace them. Today, apart from Roll-Royce, there is no other British engineering company that has the technical and manufacturing capability of designing and building an engine like the Napier Deltic engine.

6.0 Notes.

(1) The direction of travel was achieved by reversing the traction motor field winding connections, ref. 19. The Class 55 bogies were the same as the Class 37, which was itself a development of the *'Deltic*' prototype bogies, ref. 2. In service, the fabricated bogies were found to be prone to cracking and were eventually replaced by cast steel, ref. 5. & 19.

(2) The Vulcan Foundry, Newton-le-Willows, became a member of the English Electric Group of Companies in 1957. The works closed in 2002, ref. 16.

(3) Total Operations Processing System (TOPS) is a computer system for managing locomotives and rolling stock. It was developed by the Southern Pacific Railroad. The system was bought and adopted by British Rail after a presentation of the system in 1968, ref. 17.

(4) The original marine Deltic engine was rated at 2500 bhp and had a 1000 hr service life between overhauls. Rating the engine at 1650 bhp for traction duties was calculated to give 6000 hours between overhauls, ref. 2. In practice 4000 hours between overhauls was the norm, ref. 5. The overhaul was by replacement with the engine taken out and returned to the factory. A replacement with a refurbished engine would be undertaken within an 8 hour working day. Between overhauls there was an injector change at 2000 hours, ref. 2.

(5) Deltic diesel engines became a common powerplant in small, fast naval craft, refs. 10 & 18. Including: *Dark* class fast attack vessels, *Ton* class minesweepers, *Hunt* class mine countermeasures ships. The engines were also used by foreign navies, in particular the Norwegian *Tjeld* and *Nasty* class boats which were also sold to Germany, Greece and the United States Navy. The Deltic engines had aluminium alloy castings and hence a low magnetic signature suitable for minesweeping duty. The engine did not reverse so marine propulsion applications had a reversing gearbox with hydraulic clutch mounted directly on the phasing gear case.

(6) The triangular engine form was developed by Britain when the problem of correct piston phasing was solved by Mr Penwarden of the Admiralty Engineering Laboratory who suggested that one of the crankshafts needed to revolve in the opposite direction to the other two, ref. 12.

(7) When I worked for the British Polar Engine company of Govan, in the 1960's, I remember seeing Napier turbochargers being fitted to the supercharged versions of the Polar marine engines. There were also turbochargers built by Brown Boveri of Switzerland.

(8) There were reports that these scoops were being damaged when picking-up water from the troughs at high speed. The requirement for scoops was removed when the troughs were abandoned on the East Coast Main Line in January 1968. The locomotive's water capacity was increased by the space saved by removal of the scoop and reducing the engine and train heating steam generator fuel tank capacity, ref. 5.

(9) At high speeds, the vacuum brakes were found to leave little latitude for safety on two-mile block sections of the East Coast Main Line. It was decided to convert to a dual system by incorporating air brakes on the train; this was complete by July 1968, ref. 5 & 19.

7.0 References.

1. J.S. Whiteley and G.W. Morrison, *The Power of the Deltics*, Oxford Publishing Co., 1986.
2. Cecil J. Allen, G.F. Fiennes, *The Deltics a Symposium*, Published by Ian Allan, 1972.
3. Hugh W. Watson, *The Deltic Years form Prototype to Preservation*, Published by Patrick Stephens Ltd., 1989.
4. Craig W. Fellows, Paul E. Gash, *The Last Days of the Deltics*, Published by Ian Allan, 1986.
5. Brian Webb, *The Deltic Locomotives of British Rail*, Published by David & Charles Ltd. 1982.
6. British Railways, *Diesel Traction – Manual for Enginemen*, 1962.
7. Wikipedia: British Rail Class 55.
8. The Deltic Preservation Society Limited, www.thedps.co.uk
9. C.H. Wilson & W.J. Reader, *Men and Machines a History of D. Napier & Son, Engineers, Ltd. 1808 – 1958*, Published by Wiedenfeld & Nicolson, 1958.
10. Peter Webberley, *The Piston Engines of D. Napier and Sons*, Portsmouth University, Heritage Studies, MA Maritime Studies. www.ptfnasty.com/ptfDelticHist1.htm
11. Alan Vessey, *By Precision into Power, A Bicentennial Record of D. Napier & Son*, Published by The History Press, 2010.
12. Bryan Boyle, *The Napier Way*, published by Bookmarque Publishing, 2011.
13. New York City, Fire Department, 'Super Pumper System', http://fireengines.net/reviews/sp/history.htm and www.ptfnasty.com/ptfsuperpumper.htm
14. *David Napier, Engineer 1790 – 1869, An Autobiographical Sketch with Notes*, Published by James MacLehose and Sons, Glasgow, 1912.
15. Bill Gunston, *FEDDEN – The life of Sir Roy Fedden*, Rolls- Royce Heritage Trust, Historical Series No. 26.
16. Wikipedia: Vulcan Foundry.
17. Wikipedia: TOPS.
18. Wikipedia: Napier Deltic.
19. Ian Strange, 1 to 6 articles on Deltic loco design engineering, http://www.delticsounds.com/techindex.html

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Appendix 1.
D. Napier & Son Ltd., a very brief history.

A detailed history of the company is given by Wilson reference 9 and by Vessey reference 11. Here is what you need to know: David Napier was born in Scotland about 1785 and died at Surbiton, near London in 1873. David Napier's father was Robert Napier (1760-1845) a blacksmith to the Duke of Argyll at Inveraray. David's cousins were his namesake David Napier who was born at Dumbarton in 1790 and died at Kensington in 1869. He was a renowned marine engineer and contributed to the development of steamboat services, and Robert Napier (1791-1876) a notable shipbuilder and known as 'the Father of Clyde Shipbuilding'. Further details of these cousins can be found in reference 14. Reference 9 has a Napier family tree showing the connections with D. Napier & Son.

David moved to London in 1808 and after a short service under Henry Maudsley, he established an engineering business at Lloyds Court, St Giles. The company was successful in the manufacture of printing machines. In the early 1830's the works moved to York Road, Lambeth. In 1837 David's son James Murdoch (1823-1895) was brought into the business and in 1847 James was taken into partnership; thus D. Napier & Son was founded.

The product range had increased to include bullet-making machinery, coin weighing machines, hydraulic machinery, a Captain's registering compass, coin minting equipment, bullion balances, stamp perforating machines as well as the printing machines. At the height of production some 300 plus persons were employed. After the death of David in 1873 the business continued under James's direction. However latterly, he allowed the business to run down so that upon his death in 1895, only seven persons were employed. After the death of James, his fourth son Montague Stanley (1870 -1931) bought the business. The business was kept going by completion of outstanding orders, printing press repairs, and the supply of special machinery and tools for bicycle manufacturers. They also manufactured the Ritter patented rubber-tyred road skates. The business fortunes turned when Montague got involved in the design and building of motor cars and their engines. There was also a sales agreement with motoring enthusiast Selwyn Francis Edge that lasted until 1912. After buying out the shares in S.F. Edge Ltd. the Napier Company became a Public Limited Company in 1913 (it had been a Private Limited Company since 1906).

By 1903 the works had moved to Acton. The coming of the Great War in 1914 had a huge impact on the company, as well as vans, lorries and ambulances, airframes and aircraft engines were produced. This got the company into the aero-engine business. During the war Montague Napier began to develop his ideas for an aircraft engine that would eventually become the famous *'Lion*' engine. Montague Napier's health deteriorated and he settled in the South of France at Cannes in 1917. He continued to take an active interest in the company and along with the Chief Designer Arthur J. Rowledge he continued to develop the *'Lion'* engine. The Company Director was Henry T. Vane who came from Edge's sales company and Henry Tryon was Senior Development Engineer.

After the war there was a brief return to car production but by 1924 the last car was sold and Montague Napier decided to concentrate the company's efforts on aero-engines. These were some of the most innovative and powerful piston engines ever produced and include (Webberley ref. 10):

- The *'Lion'* engine famous for world speed records on land, sea and air and for wins in the Schneider Trophy Seaplane races in the 1920's.
- The *'Sabre'* engine used to power the Hawker Typhoon and Tempest fighter/ground attack aircraft of WWII.

Following a technical disagreement, Arthur Rowledge left the company and joined Rolls-Royce in 1921. His role as Chief Designer was taken over by Captain George Wilkinson who continued the close co-operation on the development of the *'Lion'* engine with Montague Napier, until Montague's death in 1931. George Wilkinson was a friend of aircraft designer R.J. Mitchell of Supermarine and designer of the *'Spitfire'*. This resulted in close co-operation in the design of record breaking aircraft powered by the *'Lion'* engine. From around 1928 onwards, Napier's employed the services of the eminent aero-engine designer Major F. B. Halford who became a director in 1935. Several H-form engines were developed including the *'Rapier'*, *'Dagger'* and *'Sabre'* engines.

During the Second World War a factory was built at Lancashire Road, Liverpool to manufacture the *'Sabre*' engine. There was also a Flight Development Establishment at Luton. The English Electric Company was asked by the Ministry of Aircraft Production to reorganise the Action works and the Standard Motor Company did the same for the Liverpool works. The Napier Company eventually became part of the English Electric group of companies in 1943. The works at Acton became a Research and Development establishment with production mainly concentrated at Liverpool. It was during this period that the *'Deltic'* engine was developed originally to power light fast naval vessels (e.g. motor torpedo boats[(5)]) and later railway locomotives and other applications, ref. 13.

During the 1960's the English Electric group of aero-engine companies were sold off to Rolls-Royce or David Paxman & Company. The Acton works closed during the late 1960's and after standing empty for many years the Liverpool works were demolished in 2004. The Napier name, however, still lives on in Napier Turbochargers Limited of Lincoln[7].

Appendix 2.
The Deltic Engine, a very brief history of the development and working of the engine.

The origin of the Deltic engine lies with the Royal Navy requirements for a high-power, lightweight, diesel engine for motor torpedo boats. During WWII these boats had been powered by petrol engines, were vulnerable to fire, and hence at a disadvantage compared to the German diesel powered E-boats.

In 1943 the Admiralty arranged for Sir Roy Fedden to head a committee to review the problems of engines for high-speed surface craft, such as motor torpedo boats and motor gun boats[5]. The final recommendation was to fund development of a high-speed diesel engine rated at 2500 hp, with promise of development to 3000 hp, whilst simultaneously doing research into gas turbines, ref. 15. The committee spent a lot of time reviewing possible manufacturers. One of the committee members, Mr Herbert Sammons, returned to his firm, D. Napier & Son Limited (he was Chief Engineer and became Managing Director in 1949), and pre-empted the situation by developing the Deltic diesel engine along the lines recommended by the committee. The whole concept of the engine was for a high efficiency, high power to weight ratio engine. The engine was in production by 1952, ref. 3.

The persons most involved with the development of the engine were: Chief Engineer Ernest Chatterton, and Chief Designers Ben Barlow and George Murray, ref. 11. Overall project management was in the hands of the Managing Director Henry Nelson the son of Sir George H. Nelson, the first Lord Nelson of Stafford and Chairman of the English Electric Company.

Over 90 design variants of the Deltic engine were schemed out over a 25 year period, ref. 11. The number of opposed piston cylinders ranged form 1, 3, 6, 9, 15, 18 and 24. The early prototype E 130/18-1 of 1946 developed 2500 bhp at 2000 rpm with a mechanical blower, at the other end of the scale was an E 185/C18-5 marine compound of 1955 developing 5500 bhp at 2000 rpm with a turbo-compressor set. The engine we are most concerned with is E 169/18-25B rail traction engine used on the Class 55 locomotive. It was a de-rated engine[4] to give a long life to drive an electrical generator, it developed 1650 bhp at 1500 rpm and used a mechanical centrifugal blower (also known as a supercharger), driven by the engine itself, for scavenging.

The Model Deltic Locomotive at Riverside Museum.

The Deltic engine is a liquid cooled, uniflow scavenged, 2-stroke cycle, opposed piston, diesel engine. In cross section the engine has a triangular cylinder arrangement in the form of an inverted capital Greek letter delta ∇ – hence the name *'Deltic'*. The reason for the delta configuration is explained by Bryan Boyle in reference 12. This form of engine had several advantages:

- The opposed piston design avoided cylinder heads
- The two piston heads can be used to control the scavenging and exhaust by means of cylinder ports thus avoiding the use of poppet valves and associated valve gear.
- The uniflow scavenge method was more efficient in clearing the cylinder of the exhaust gases compared to the alternative loop or cross flow methods of scavenging.
- The engine balance was improved and hence vibration was reduced compared to a conventional engine.

There were of course some disadvantages:

- Two crankshafts and crankcases were required for one cylinder bank, which added to the complication and had a weight penalty.
- A gear train (gearbox) was required to phase the opposing pistons and transmit the power from each crankshaft to a single output shaft.
- Multiple fuel injector valves per cylinder were required in some applications (the Class 55 locomotives only required one CAV type injector valve per cylinder) to give uniform combustion.

Although the engine could be built to operate in any orientation it was built with the CA crankshaft at the bottom, which also incorporated an oil sump. The main body of the engine was made of aluminium alloy to keep the weight to a minimum. The model cut-away shows the AB crankshaft with the exhaust and inlet pistons and the fork and blade connecting rods to form the big end bearings.

A key requirement to getting the engine to work was that one of the crankshafts must turn in the opposite direction to the other two[6]. This can best be seen in the following animation: http://www.acwhyte.droppages.com/downloads/animations/Napier_Deltic_Engine_animation_with_text.gif.

Notice that as the crankshafts turn for a brief period both pistons move in the ***same*** direction. Bryan Boyle explains the reason for this, in reference 12, as due to the required phase angle lead (20 degrees) of the exhaust piston which has started on its working stroke, but the scavenge piston is still completing its compression stroke. With 3 cylinders per bank and 6 banks of cylinders, this gave an 18 cylinder firing sequence with a power stroke every 20 degrees. The result is a relatively smooth output torque with a low ratio of maximum to mean torque.

The power transmitted from each crankshaft was combined into one output shaft by means of quill-shafts and phasing gears. The direction of rotation of the output shaft was ensured by means of idler gears. The phasing gear also drives some ancillary equipment such as: auxiliary generator, the blower, the engine governor, oil pumps, and the radiator cooling fans via double universal joints.
