Model Locomotive Research

A brief survey

By Jim Ewins

One of my pre-occupations in the field of model locomotives is that of researching into what makes them tick. In my view mechanical engineering is applied physics and models are a branch of mechanical engineering which I am able to practice at home in accordance with my own interpretation of the laws of physics. Having theories about various matters is sterile unless they can be and are tested by experiment. All the engines I have so far constructed have had an element of experiment about them to test the validity of my ideas. Needless to say, not all aspects of my endeavours have had a positive result and were it possible to predict with certainty the results of all innovations, experiment would be superfluous.

Research into model locomotive design has in the main followed the course of that in full size practice wherein the early work was on the basis of 'cut and try' and only later was there any scientific approach made to testing and evaluation. Unfortunately for the model case, innovators relied (and some still do) on regarding full size criteria as being similarly applicable to models. It does not require a very deep knowledge of the physics of fluid flow heat transfer and thermodynamics to be aware that when one reduces the scale of a piece of apparatus to 1/10th size say, that things are liable to be different. In trying to calculate the magnitude of this difference one is up against a number of imponderables and it is only by carrying out tests that the matter can be resolved- this is research.

Building equipment and carrying out the necessary testing is a time consuming activity which detracts from finished model output. A well known model locomotive designer writing to me on the 6th of July 1962 said - "When I get my test stand finished I hope it will be possible to get down to such things as accurate measurement of power output, drawbar pull, fuel consumption, superheat temperature, steam chest pressure etc. But it will be a little time yet." He can say that again! After a quarter of a century there is not much evidence of a test stand! There are however plenty of designs. Wouldn't it have been better if the test stand had preceded the designs?

Delving back into past model engineering literature I have been trying to locate reports of research from the earliest days. Dr James Crebbin appears to have been one of the earliest investigators of overall loco design involving Solid fuel boilers and in fact it was he who alerted me to the possibility of using radiant superheaters. He fitted one to his Cosmo Bonsor. Which according to Bill Carter writing in the S.M.E.E. Journal started as a 4-4-2 four cylinder tandem compound and finished up as a 4-6-0 two-cylinder simple. The radiant superheater he used (which is still in it) was a simple "hairpin" pipe up one firetube into the firebox and back down another. This engine which was in 4 1/2" gauge is reported to have hauled a passenger at the first Exhibition in 1907. Things have come some way since then!

After Mr. Crebbin there seems to have been an era during the thirties when a few brave souls were venturesome enough to kick over the traces of the Greenly philosophy of large boilers and small cylinders and adopt a procedure of suck it and see. It takes a great deal of courage to invest much time and money in a project which may turn out to be an abject failure. Among this band of workers may be mentioned Mr.G.Willoughby, Mr.C.M.Keiller and of course L.B.S.C. I do not know whether trial and error methods can be classed as 'research' but there is no doubt that results can be achieved this way and in the absence of a sound technical education as was the case of L.B.S.C., this is the only way to make progress. In his case this process was greatly speeded up by his being able to devote all his time to producing many engines of a rudimentary nature and being able to test them under what was then typical working conditions. Some of his pronouncements in the M.E. were greeted with derision by the more erudite but he had the great advantage that he could point to things he had done which the others had not. I have a certain sympathy with this!

In the thirties also, Mr. E.J.Linden and Keiller (l) devoted much of their time to research in connection with miniature injectors. Prior to this several experimenters introduced injectors, that operated after a fashion but which could not be relied upon and needed the back up of mechanical or hand pumps. This is an area where a sound technical knowledge of how injectors work pays great dividends which enabled Linden to virtually tie things up whilst L.B.S.C. was left floundering. Linden never published his findings and it was left to Keiller to publish designs based on Linden's work. Even today we see injectors made to L.B.S.C's instructions by manufacturers who ought to know better. Basil Palmer (2) in South Africa published a useful article based upon Eric Rowbottom's work on injectors for use at high altitudes and higher pressures. Again from South Africa there was an interesting account of laboratory testing of a 3 1/2" gauge Britannia Boiler by Mr. Busbridge published in the M.E (5).

Looking through Journals of the Society of Model and Experimental Engineers there is little experiment reported apart from three articles of mine (3). Way back in 1948 a locomotive test bench was made by the combined efforts of Prof. Chaddock and Messrs. Huttont Wildy and Latta. This was a well made equipment but suffered from the intrinsic drawback of slip between the wheels of the loco being tested and the rollers which applied the load allowing only small values of draw bar pull loads to be applied and measured accurately. One set of results with this equipment has been published by G.W.Wildy (4) which demonstrates the difficulty mentioned above. Mr. Bert Woodford of the Malden Society has built a similar test stand which he showed at the 1987 Model Engineer Exhibition this had the same limitations but he has supplemented his experiments with track runs using a dynamometer. Mr. Woodford's test-bed results are similar to mine in that efficiencies of the order of 4% are obtained whereas on the track efficiency figures of half this value are normal, similarly at I.M.L.E.C. A key piece of research was carried out by Brian S. Lee in 1968 using an electronic sensor to produce indicator diagrams in small models. His work was confined to an unsuperheated engine and showed severe back-pressure when the engine was driven hard. I used this equipment on a small vertical engine at a Model engineer Exhibition and found the same effect. At the time this work was not understood by the few who knew about it and a suggestion of mine to extend the investigations to a well superheated engine seems not to have been taken up.

As I write issue No. 3813 of the Model Engineer is to hand, in which appears a report of some research by Basil Markham (4) on the collapsing pressure of annealed copper tubes. This is a useful piece of work which confirms that which I have several times quoted and throws some doubt on data which appears in Mr. Evans' book 'Model Locomotive Boilers'. Mr. Markham has shown that manufacturing variations in nominal tube diameter and wall thickness can result in tube collapse under boiler test pressure if sufficient allowance has not been made for this. I have always recommended that test pressures should not exceed half experimentally known collapsing pressures and that test pressure should be twice working pressure. In this way there is ample margin to allow for manufacturing, tolerances and the accidental flattening of tubes during the boiler construction. Also just published in M.E. issue No. 3814 is a report from Mr. H.F.Atkinson on "Testing Copper Joints". Mr. Atkinson concludes that Lap, Joggled Lap, Plain Butt and Flanged joints if silver soldered with Easiflo yield strengths in excess of that of the parent plate. This is as I discovered some years ago in the laboratory and have demonstrated at talks I have given to various Societies. He concludes, as I have held for many years, that flangeless joints might well be considered in copper boilers. However Mr. Atkinson's tests on a Plain Butt joint were in pure tension which does not occur in practice so don't use these joints on the main barrel. The above brief survey is probably by no means complete and if readers should know of additional work I should be happy to include this in a future up-date of this article and re-issue in due course.

As a result of the above endeavours engines are now built which have vastly improved performance than hitherto thought possible. If one had lived before the turn of the century and been told of the goings on at tracks up and down the country now many would have said "rubbish" as indeed the late Henry Greenly was apt to do. We owe it to the likes of L.B.S.C. who, through some intuitive process, was driven to try things another way such that the break-through came. To try to get an idea of what went wrong in those early days I looked back through some of the first Model Engineers and found an article in Vol. 2 No. 14 Feb 1899 describing an engine made by a Mr. S.G.E.Copestake. Fortunately very complete details were given for this engine which were as follows:

Diameter of cylinders (brass)	1 5/8"
Stroke of Pistons (brass with steel rod)	2 1/4"
Diameter of driving wheels (brass)	6"
Diameter of bogie wheels (brass)	2 1/4"
Wheelbase between driving wheels	9"
Wheel base (total)	24"
Thickness of frames (steel)	1/8"
Height of platform from rail	5 1/2"
Width of platform	11 1/2"
Water in boiler	1 1/2 galls
Diameter of boiler	6 5/8"
Length of boiler including firebox	20 1/2"
Heating surface of firebox	137 sq.in.
Heating surface of tubes	1066 sq.in.
Grate Area	40 sq.in.
Chimney diameter	1 3/4"
Diameter of pump rams (two)	3/16"
Weight of engine in working order	145 lbs.
Weight of tender in working order	66 lbs.
Extreme length of engine over tender and buffers	63"
Gauge	7"
Working pressure	40 p.s.i
Fuel	Hardwood Charcoal

In the text it is stated that the boiler had 79 brass tubes 3/8" outside diameter and thick enough to take a fine thread. The engine is stated as being capable of taking one person up a one in ninety gradient and two on the level and is referred to by the editor as "a powerful model for its size". What were they doing wrong?

I have devised a set of criteria embodied in four factors which are shown at the end of this article by which the vital parameters of model locos may be compared and those of "good" engines taken as the desirable ones so that one might compare these with other existing and proposed designs to access their likely characteristics. I have now got this technique into a computer program which has come up with a read-out for the above engine. The first parameter to notice is that of the boiler factor (E_B=90) which is very close to that which gives good results today. Unfortunately this parameter contains the Keil1er tube factor (Kt) which should be around 80 but is in fact 178. So here is the first mistake. Our friend Copestake has (presumably) tried to get so much heating surface into the tubes (1066 and all that) that he has used too many small tubes.

The next error lies in the engine factor E_E which is 0.077 instead of being around 0.15. E_E involves the cylinder dimensions the grate area and wheel diameter from which it is clear that the grate is disproportionately large compared with the rest. This was a common fault with early designs. Because of the low values of E_E and E_B the value of E_O which denotes a balance between the 'engine' and the 'boiler' is also low.

The nominal tractive effort comes out at 56 lbs. but the program works this out for a boiler pressure of 80 p.s.i. instead of the 40 p.s.i. which was used. 28 lbs. tractive effort is pretty feeble for a 1 1/2" scale loco now-a-days and accounts partly for the poor performance. The adhesive weight being about half the weight of the engine would have been around 72 lbs. giving a factor of adhesion of 0.4 not much chance of slipping here and not much chance of the resulting feeble exhaust blast making much impression on the large grate area of 40 sq. in. No wonder charcoal was used for fuel. I suppose coal would not stay alight under those conditions and a coal fire if it had been tried would have burnt most inefficiently if at all. We now know (at least some of us do) that coal fires need to be driven hard to burn efficiently.

The computer was next set the task of redesigning the engine by retaining the same wheel diameter and stroke whilst it was given some latitude with the other parameters. This is achieved by inserting limits to the range of scan of the parameters that one wishes the computer to work on, whilst reducing this range to zero for those required to remain unaltered. This resulted in the revised design in which the following modifications are called for. Increase bore to 1.9 inches. Reduce grate area to 28 sq. inches. Reduce number of tubes to 28. Increase tube bore to 0.45 inches. Increase tube length to 16 inches. The revised engine would have had a nominal tractive effort of 108 lbs. and would have needed the adhesive weight to be increased to 168 lbs. This could have been achieved by making the boiler from 1/8" plate instead of 1/16" which would have been necessary for the higher working pressure built into the program. Additional weight could have been obtained by making the frames from 3/16" plate instead of 1/8". To sum up then assuming Mr. Copestake wished to use the 6" wheels and 2 1/4" stroke, he should have (1) used larger cylinders, (2) Cut down the grate area, (3) reduced the number of tubes (4) used larger tubes (5) made the boiler from 1/8" copper and worked it at 80 p.s.i. This latter modification would have gone a long way towards getting the adhesive weight up to that recommended in the program and further progress in this direction could have been obtained by making the frames from 3/16" material instead of the 1/8" used. Another possible improvement would be the substitution of an 1 3/8" chimney choke tube instead of the 1 3/4". And finally a radiant superheater would have really made it get up and go.

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Engine factor EE = $\dfrac{\textbf{Swept Volume Of Cylinders Per Revolution}}{\textbf{Grate Area x Driving wheel Diameter}}$

Boiler Factor EB = $\dfrac{\textbf{Grate area in sq. in. x Tube Length in in.}}{\textbf{Number of tubes x (Tube diameter in inches) squared}}$

Overall Factor Eo = EE x EB

Tube Factor Kt = $\dfrac{\textbf{Length of Tubes in inches}}{\textbf{(Diameter of Tubes in inches) squared}}$