APPENDIX 1

ENGINE DUES

Boulton and Watt provided very little material assistance in the supply of steam engines. They limited their involvement to the supply of drawings, a limited number of components, mainly associated with the valve gear, and assistance in the installation and operation of the engine. The mine owners were responsible for the procurement of all other components, including cylinder, piston, beam, engine house, boilers and pit gear. Boulton and Watt elected to obtain their return by payment of dues in respect of their patent. The dues levied were based on the coal saved when compared to an equivalent Newcomen engine. This was a difficult proposition for it was unlikely a direct equivalent could be found, and so Watt developed a means of determining a hypothetical equivalent.

Given this equivalence it was feasible to calculate the coal consumed by it in fulfilling the same task as the engine to be supplied by Boulton and Watt. The difference between the two consumption figures gave the saving, and Boulton and Watt claimed as their due one third of the cost of the saving achieved. The literature without exception does not indicate how this saving was arrived at, leaving it as a bald statement of fact. However, in the Boulton and Watt correspondence deposited in Birmingham Central Library and reproduced by Tann was a document relating to a proposed engine for theHallamanin mine in which the method of arriving at the savings was developed, and is described below.

An account of the Consumption of Coals by the two Eastern and the Middle Fire Engines at Poldice Mine, and Calculations therefrom of the Coals which would be consumed by a Common fire Engine equal in power and length of Stroke to the new Engine erected at Hallamanin Mine according to the invention of James Watt[1]

NEWCOMEN ENGINES AT POLDICE

Poldice	Cyl dia	Depth fms	Box ins	Strokes per min	Stroke length ft	Load psi	Bushel coal consumed per 30 days
No 1	66	33	17	6	5.5	5.7	3,945
No 2	60	25	17	6	5.5	5.2	2,979
No 3	66	63	12	5	5.5	5.4	2,864

Watt assumed consumption of coal was proportional to the area of the cylinder, all else constant.

Normalise to a cylinder dia of 60" and 6 strokes per min.
Engine No. 1: 3,260 bushels per 30 days
Engine No. 2: 2,979 bushels per 30 days
At 5 strokes per min, Engine No. 3: 2,367 bushels per 30 days
and at 6 strokes per min: 2,840 bushels per 30 days

Hence, average monthly consumption: 3,027 bushels per 30 days
At an average load of: 5.43 psi

Given for a 60" cylinder, stroke 5.5' making
6 strokes per min, and load equal to 1 psi, coal consumed: 1,920 bushels per 30 days
Thus additional coal consumed for an average load of 5.43psi: 1,107 bushels per 30 days
Or at an average load of 5 psi, coal consumed: 1,018 bushels per 30 days
Thus for each additional load of 1 psi, coal consumed: 254.58 bushels per 30 days

Load	Average of Poldice Engines 60" cylinder, stroke 5.5', 6 strokes per min. Coal consumed in 30 days		Newcomen Equivalent of B & W at Hallamanin 49" cylinder, stroke 8', 6 strokes per min. Coal consumed in 30 days	
psi	Total Load lbs	bushels	Total Load lbs	bushels
1	2,827.4	1,920	1,885.7	1,861.8
2	5,654.9	2,175	3,771.5	2,108.7
3	8,482.3	2,429	5,657.2	2,355.5
4	11,309.7	2,684	7,543.0	2,602.4
5	14,137.2	2,938	9,428.7	2,849.2
6	16,964.6	3,193	11,314.4	3,096.1
7	19,792.0	3,447	13,200.2	3,343.0

WATT ENGINE AT HALLAMANIN

The Watt engine at Hallamanin, installed in 1778, was a single acting engine with the following dimensions:

Cyl dia: 40 ins
Stroke: 8 ft
Load: 10.5 psi
Strokes per min: 6

It was required to raise a column of water equal to a pressure of 10.5 psi on the piston.

Newcomen equivalent:

Loaded at: 7 psi
Equivalent cylinder dia: 49 ins
Given that a Newcomen 60" cyl dia consumes: 1,920 bushels with a load 1 psi
Coal consumed by 49" cyl dia: 1,280 bushels with a load 1 psi
At a load of 5 psi: 1,959 bushels per 30 days
Thus for each additional load of 1 psi, coal consumed: 170 bushels per 30 days
For a stroke of 8', coal consumed: 247 bushels per 30 days

	Watt			Conventional [2]
Pump column: 12" dia and 46 yds high:	144.0	_dia^2_	area:	113.11 sq ins
	3.6	_1/40*dia^2_	height:	1656.00 ins
	147.6	_(Watt used 148)_	vol:	187,313.00 cu ins
Height of column of water in pump:	46.0 yds			108.40 cu ft
Weight of column of water:	6,790.0 lbs	_(147.6 * 46)_		6,775.00 lbs[3]

Coal consumed: 2,504 bushels in 30 days *(interpolate table above)*

This assumes that the engine ran continuously for 30 days at 6 strokes per minute. This may not be the case. The actual number of strokes achieved in the 30 days will be given by the stroke counter fitted to the engine. Thus the coal which would have been consumed will be given by the ratio of the strokes given by the counter to the strokes in 30 days:

$$\text{Actual coal consumed:}\quad \text{Coal consumed in 30 days } \mathit{x} \; \frac{\text{strokes given by counter } \mathit{x} \text{ 30}}{8{,}640}$$

Where 8,640 is the number of strokes in one day at 6 strokes per minute.

Thus for contract purposes, the savings effected by a 40" Boulton & Watt engine are:

2,938 - 2,509 = 429 bushels in 30 days
Annual savings = 5,220 bushels

The cost of coal in 1760 was of the order of £1.00 per ton delivered at the mine.[4]
and the weight of a bushel of coal was 84lb.[5]

Thus coal saved in 1 year: 5,220 * 84
or: 195.75 tons
at a cost of: £195 15s 0d

Thus premium payable to Boulton and Watt on the Hallamanin engine: £65 5s 0d per annum.

The above example indicates method rather than a precise example. The Boulton and Watt paper stopped short of determining the actual premium payable. The dues of £65 5s 0d, whilst in line with dues at the time for that size of engine, can only be considered approximate resulting from the uncertainty in the relationship between magnitude of the volume and weight units used and the cost of coal in 1778.

This method was far too complex for the Cornish mine owners, and was never fully accepted. It was also recognised by Watt that those months incurring the greatest charges were also those for which there was the least output. Similarly, the amount to be paid could only be determined after it had been expended. In 1780 an alternative came into operation based on the area of the cylinder and the length of the stroke. An alternative approach was based on the load per square inch on the piston. Ultimately, the dues levied were fixed at an annual rate at the time of contract award.[6]

NOTES

[1] The three engines at Poldice were Newcomen engines. The Hallamanin engine was erected in 1778, thus being amongst the first to be installed in Cornwall. Tann, J. *The Selected Papers of Boulton and Watt*, vol 1, (MIT Press, Cambridge, Massachusetts, USA, 1981), 281 – 85. Dickinson, H W. and Jenkins, R. *James Watt and the Steam Engine*, (2 edn. Encore Editions, London, 1981), 341.

[2] Watt used an approximation, this column is the more conventional method, thereby justifying Watt's approximation.

[3] 1 cu ft weighs 62.5 lbs

[4] Barton, D B, *The Cornish Beam Engine*, (D Bradford Barton, Truro, 1965), note 2, 20.

[5] This can only be considered approximate, as the bushel is a volume measure. Its weight therefore will depend on the size of the pieces of coal. Pole, W. *A Treatise on the Cornish Pumping Engine*, (John Weale, London, 1844), 157.

[6] Dickinson, H W. and Jenkins, R. (1981), 333 – 34.