Open Rails

Steam Locomotive Steam Heat Model

Peter Newell
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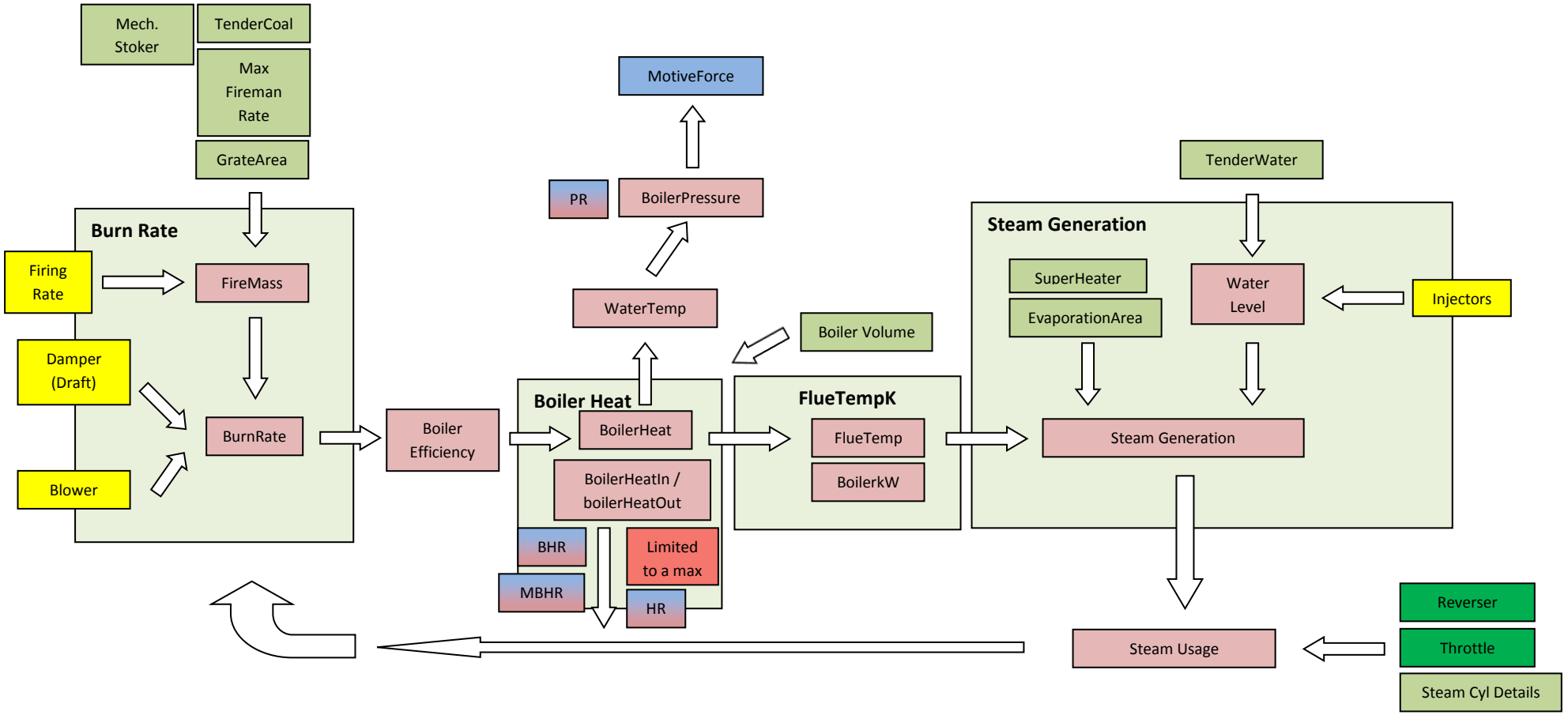
Steam Locomotive – Heat Model - Overall



AI Steam Control

Heat Ratio (HR) – determines burn rate - based on the ratio BoilerHeatOut / BoilerHeatIn

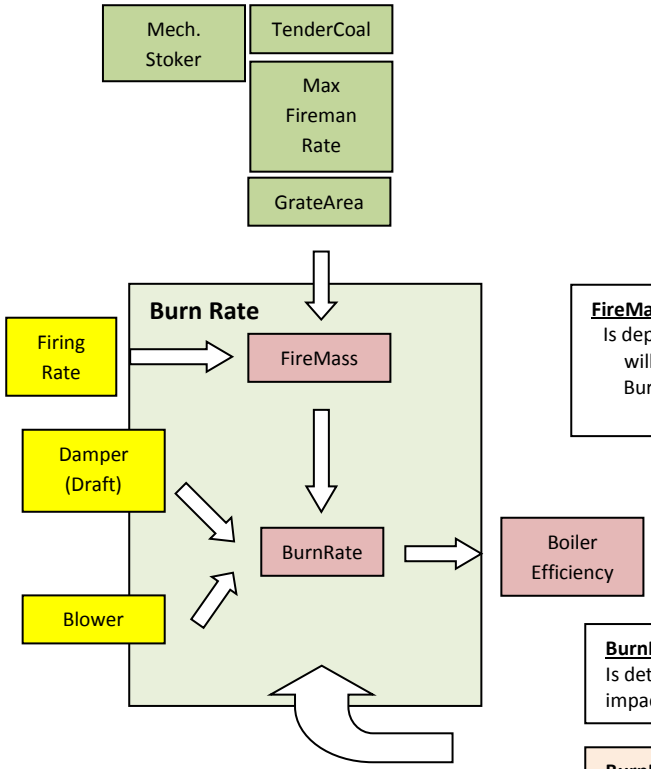
Pressure Ratio (PR) – increases burn rate if pressure drops – based on ratio MaxBoilerPressure / BoilerPressure

Boiler Heat Ratio (BHR) – decreases burn rate if boiler heat is exceeding max value – based on ratio BoilerHeatOut / BoilerHeatIn

Max Pressure Boiler Heat Ratio (MBHR) – decreases burn rate if maximum boiler pressure (including safety valve operation) is exceeded – based on ratio xxxxx

Limitations	AI Control
Controls	MotiveForce
Manual Only	Eng File Inputs
Ai / Manual	OR Calcs

Steam Locomotive – Heat Model – Burn Rate Module



FireMass

Is dependent upon the amount of coal burnt and the coal feed rate. The firemass typically will be maintained around the ideal fire mass, which is determined by the grate area. Burning coal beyond the ability of the fireman to feed the fire will result in decreased firemass.

BurnRate

Is determined by a table relating steam consumption to lbs of coal burnt. The GrateLimit will impact upon the ability of the fire to produce heat (and steam) energy.

BurnRate Limitation

i) Can't exceed firing rate indefinitely

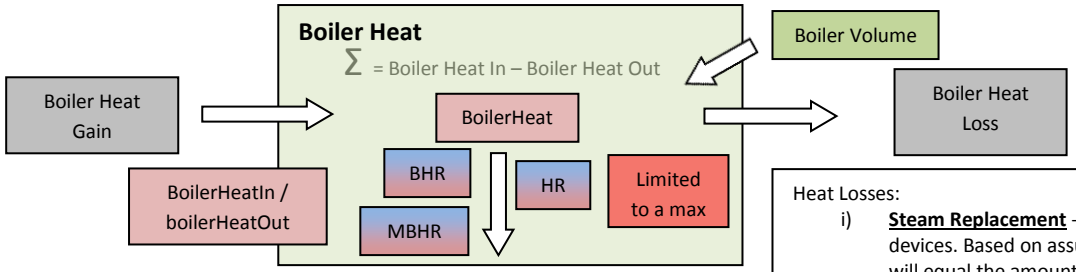
ii) Exceeding the GrateLimit will reduce ability of fire to produce heat (modelled through the use of Boiler Efficiency)

Steam Locomotive – Heat Model – Boiler Heat Module

AI Steam Control

Boiler Heat Ratio (BHR) – decreases burn rate if boiler heat is exceeding max value – based on ratio BoilerHeatOut / BoilerHeatIn

Max Pressure Boiler Heat Ratio (MBHR) – decreases burn rate if maximum boiler pressure (including safety valve operation) is exceeded – based on ratio xxxxx



AI Steam Control

Heat Ratio (HR) – determines burn rate - based on the ratio BoilerHeatOut / BoilerHeatIn

Pressure Ratio (PR) – increases burn rate if pressure drops – based on ratio MaxBoilerPressure / BoilerPressure

Heat Gain:

Fuel Burn - Heat generated by the burning of the fuel

Heat In = Fuel Burnt = Fuel Burnt x Fuel Calorific x Boiler Efficiency / (Specific Heat Fuel x Fire Mass)

Heat Losses:

i) **Steam Replacement** - Heat required to replace steam used by the cylinders and other steam devices. Based on assuming that water mass heat remains the same, then assume heat "lost" will equal the amount of heat needed to raise temp from current boiler water temp to current boiler steam heat, for the amount of steam used. Water mass heat will change when water replacement occurs.

Heat "out" = Steam Used x (Boiler Steam Heat – Boiler Water Heat)

ii) **Water Replacement** - Heat required to heat replacement water coming into boiler from injectors. This will be the amount of water times the heat required to rise temp from injector water temp to boiler water temp

Heat "out" = Water Input x (Boiler Water Heat – Injector Water Heat)

See Iniector model

Injector Types Modelled (Based on Sellers Injectors)

Live Steam Type – use live steam from the boiler for water propulsion, feedwater is feed into the injector at ambient temperature (65F) and steam is then used to "push" water into the boiler, typically water will be delivered into the boiler at a temperature of up to 269F.

- Delivery water temp – max 269F – assume heat loss differential (Boiler Heat BTU)
- Small boiler steam usage – small increase required in heating to compensate – based on steam to water rates?

Exhaust Steam Type – in this type exhaust steam is used to heat the feedwater, as well as provide the propulsion for injecting water into the boiler. This returns some heat to the boiler that otherwise would be vented, typically water will be delivered into the boiler at a temperature of up to 300F.

Advantages of exhaust injectors –

- Delivery water temp higher than above – assume 40F linear increase on above model
- Reduce steam loss from boiler as waste steam returned to the boiler – use rates to determine steam return (reduced boiler mass loss)
- Reduces cylinder backpressure (by about 10%) ? how to model

BoilerHeat Limitation

A boiler is only capable of holding a certain amount of heat; this will be determined by the volume of the boiler and the boiler operating pressure. Once this boiler heat value is exceeded, the boiler will start exhaust steam through the safety valve in an effort to reduce the heat value.

Typically the locomotive boiler works on the principle of "heat transfer", ie heat put into the boiler is used by the cylinders straight away and therefore the boiler heat value should normally not be exceeded.

Example Locomotive States

State 1 - Steady State

Locomotive is at rest, with a full boiler, and @ operating boiler pressure - as an example, and using the steam tables, a saturated locomotive with 160psi would have the the following temps. Water - 371F, Steam - 1196F, Input water heat (water delivery temP) - 200F

In this state BoilerHeatIn (heat generation by coal burning) = BoilerHeatOut (heat to be replaced = 0

State 2 - Steam Usage (through cylinders), but no water input

In this state, to maintain heat balance, the heat input required would only be that necessary to generate replacement steam. Given that no water is being added to the boiler, and that the water in the boiler is @ 371F already, the only heat required to bring us back to the "steady state" condition, is that necessary to heat the water from 371 to 1196F to create steam. Thus for example if the loco is using 10,000 lb/h of steam. This is a heat reduction that needs to be balanced by a heat "input".

Replacement Steam (Heat Input required) = 10,000 (Steam heat - water heat)

State 3 - Loco stationary, but injecting water into the boiler.

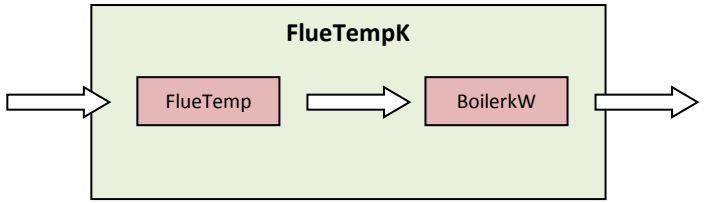
In this state, the water temp in the boiler is 371F, but we are adding water at a temp of say, 200F, thus we need to add sufficient heat to the boiler to heat the water from 200 to 371F, and return it to the steady state condition. Thus for example if the loco is injecting 5,000 lb/h of water. This is a heat reduction that needs to be balanced by a heat "input".

Water Heating (Heat Input required) = 5,000 (Water heat - input water heat)

State 4 - Loco in motion and injecting water

In this state, the locomotive is using steam and injecting water, and therefore it would be a combination of state 2 & 3, to maintain steady state.

Steam Locomotive – Heat Model – FlueTemp Module



FlueTempK is determined by summing the change in Boiler Heat (ie BoilerHeatIn – BoilerHeatOut).

FlueTempK = ΔBoilerHeat / Boiler Evaporation Area

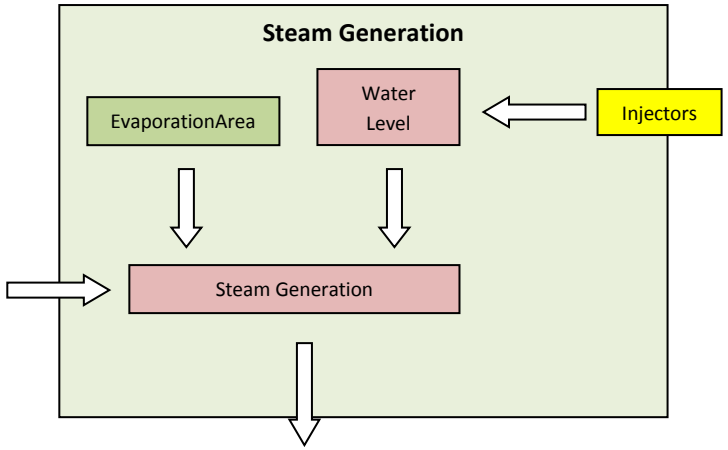
FlueTempK is currently not limited, and will continue to rise until a maximum figure; according to the change in boiler heat is reached.

BoilekW is principally determined by the FlueTemp.

BoilerkW = FlueTemp * Evaporation Area

BoilerkW is currently not limited, and will continue to rise until a maximum figure; according to the FlueTemp.

Steam Locomotive – Heat Model – Steam Generation Module



SteamGeneration (EvaporationLbpS) is principally determined by the BoilerkW, and is a conversion of kW into LbpS of steam generation.

Evaporation = BoilerkW (converted to lbps)

Steam Generation Limitation
A boiler relies on heat transfers, and is only capable of producing a finite amount of steam output.
Some of these limitations include:

i) Max Steam Generation – typically approx. 15 x Evaporation Area (this is not a hard limit – see text box to right)

ii) Max Steam Usage – can exceed generation for short periods of time – time will be dependent upon the boiler volume, and subsequent heat loss, and water mass loss (ie can the injectors keep up with the load). It is not limited; however steam generation should be limited to maximum evaporation rate.

Steam Generation

The steam generation value is an "indicative" number only, and it therefore is not a hard limit for the maximum output of the boiler. It is possible to exceed the steam generation figure under certain circumstances for short periods of time. The figure is an average value over the hour.

It appears that the following factors will limit the steam generation output –

Injector Limit - the amount of steam that can be produced will be limited by the amount of water that can be injected into the boiler. Undersized injectors would limit steam generation rate.

Discharge Limit - this appears to be related to the exhaust blast limit and the draft rate.

Grate Limit - This appears to be reached when the amount of coal being combusted reaches approx 140-150 lbs/SQFT Grate Area. Trying to burn any additional coal will not produce anymore heat.

Firing Rate - the rate at which a fireman can feed the fire will determine how much heat energy can be "injected" into the boiler. The use of mechanical stokers have overcome this issue, provided the grate area was large enough to support it.

Evaporation Area - will determine how efficient heat energy can be transferred into the boiler.

Fuel calorific - fuels with lower fuel calorific values will produce less heat per SqFt Grate Area, and consequently it also acts as a limit to steam generation.

Steam Locomotive – Heat Model

Required Input Parameters

The OR Steam Locomotive Heat Model (SLHM) should work with default MSTS files; however optimal performance will only be achieved if the following settings are applied within the ENG file. ***The following list only describes the parameters associated with the SLHM, other parameters such as brakes, lights, etc still need to be included in the file*.** As always, make sure that you keep a backup of the original MSTS file.

Parameter	Description	Recommended Input Units	Suggested settings	New or Existing	Typical Examples
General Information					
WheelRadius (x) (in engine section)	Radius of drive wheels	Distance – m, in	As per loco specs	Existing	WheelRadius (0.648m) WheelRadius (36in)
Boiler Parameters					
BoilerVolume (x)	Volume of boiler	Volume – cu ft, cu m	This parameter is not overly critical, and where an actual value is not available, use EvapArea / 8.3 as an approximation	Existing	BoilerVolume ("220*(ft^3)") BoilerVolume ("110*(m^3)")
ORTSEvaporationArea (x)	Boiler evaporation area.	Area – sq ft, sq m	As per loco specs	New	EvaporationArea ("2198*(ft^2)") EvaporationArea ("194*(m^2)")
SuperHeater (1.0)	Superheating capability	Factor	1 = saturated only >1 = superheated	Existing	
Locomotive Tender Info					
MaxTenderWaterMass (x)	Water in tender	Mass – lbs, kg 1 uk gal = 10lb 1 us gal = 8.34lb	As per loco specs	Existing	MaxTenderWaterMass (36500lb) MaxTenderWaterMass (16000kg)
MaxTenderCoalMass (x)	Coal in tender	Mass – lbs, kg	As per loco specs	Existing	MaxTenderCoalMass (13440lb) MaxTenderCoalMass (6000kg)

Parameter	Description	Recommended Input Units	Suggested settings	New or Existing	Typical Examples
Fire					
ORTSGrateArea (x)	Locomotive fire grate area	Area – sq ft, sq m	As per loco specs	New	
ORTSFuelCalorific (x)	Calorific value of fuel	Energy Density -	Internet search – for coal use a default value of 13700 btu/lb	New	FuelCalorific (13700btu/lb) FuelCalorific (33400kj/kg)
ORTSSteamFiremanMaxPossibleFiringRate(x)	Maximum fuel rate that fireman can shovel in an hour	Mass – lbs, kg	Use following as defaults: UK – 3000lb/h US – 5000lb/h Aus – 4200lb/h	New – alternate value to MSTS	SteamFiremanMaxPossibleFiringRate(4200lb/h) SteamFiremanMaxPossibleFiringRate(2000kg/h)
SteamFiremanIsMechanicalStoker (x)		Factor	0 = no stoker 1 = stoker	Existing	SteamFiremanIsMechanicalStoker (1.0)
Steam Cylinder					
NumCylinders (x)	Number of steam cylinders	Factor	As per loco specs	Existing	NumCylinders (2)
CylinderStroke (x)	Length of cylinder stroke	Distance – m, in	As per loco specs	Existing	CylinderStroke (26in) CylinderStroke (0.8m)
CylinderDiameter (x)	Diameter of cylinder	Distance – m, in	As per loco specs	Existing	CylinderDiameter (21in) CylinderDiameter (0.6m)

Notes – Existing – means a parameter in original MSTS or added through MSTS BIN
New – means added as part of OR development

Possible Locomotive Reference Info:

i) Steam Locomotive Data - http://orion.math.iastate.edu/jdhsmith/term/slindex.htm

ii) Example Wiki Locomotive Data - http://en.wikipedia.org/wiki/SR_Merchant_Navy_class

Driving Tips

A steam locomotive works is effectively a heat engine which converts heat to mechanical work. To achieve optimal performance the outgoing mechanical work needs to be balanced against the incoming heat generated by the fire. If the locomotive heat source (fire) cannot generate enough heat to provide the outgoing force required then the locomotive will stop working. Thus heat energy is being converted to a mechanical force, and thus it needs to be remembered that any conversion process will inherently have losses in it.

In driving the locomotive, the following points may assist the driver. The values referred to are in the HUD view (Shft – F5).

i) **Heat Balance** - Heat input must be greater than the corresponding output force (or equivalent heat output) – watch the "Thermal In" and "Thermal Out" values to ensure that that the "Thermal In" generally is maintained greater than the "Thermal Out" value over prolonged periods of time.

ii) **Heat Capacity** – The amount of heat stored in the boiler will determine the amount of heat available to be released as a working force – typically when the OR first starts the locomotive will be in a "cold" state - watch the "Temp: Flue" as you start moving, this value should start increasing as you move off. Maximum steam generation will happen when this value is at its highest value. The flue temp will increase whilever "Thermal In" is greater than "Thermal Out". Increasing and decreasing heat values is not an instantaneous process, the driver and fireman would need to think ahead to cater for the required heat capacities. For example a locomotive standing still doesn't need as much heat in as a locomotive that is working hard – watch the "Temp: Flue" value.

iii) **Boiler Efficiency** – Is a measure of the efficiency of a locomotive to do work and is determined by dividing the total output effort of the locomotive by the total input effort of the locomotive. In an ideal world this should be equal to 1, indicating that the input = output, however in reality it generally operates with an efficiency value of between 0.8 and 0.4, thus indicating that typical losses and that the input effort needs to be greater than the output effort. A typical locomotive is most efficient when it is running a lower combustion rates compared to higher combustion rates - watch the "Boiler Eff" value to try and ensure best efficiency whenever possible.

iv) **Combustion Rate** – the combustion rate of a locomotive is typically quoted in pounds (lbs) of coal burnt per square foot of the grate area. (lbs/Sq FtGA). Typically the best efficiency of the locomotive will be achieved at a combustion rate of 40 lbs/Sq FtGA, as the combustion rate increases the efficiency will decrease. Typically most locomotive designers attempted to maintain service values of less than 120 lbs/Sq FtGA. This was achieved by increasing fire grate areas as appropriate – watch the values of "Fire: Comb". The typical Grate Limit (point at which no further steam will be produced) for a locomotive is in the order of 140 – 160 lbs/Sq FtGA.

v) **Mechanical Stoker** – In locomotives with larger fire grates, it was often difficult for a fireman to keep feeding the fuel required to support the maximum combustion required, and as a consequence mechanical stokers were fitted to these locomotive to increase the fuelling rate. It should be noted that it was still ideal to not exceed the 120 lbs/Sq FtGA combustion value, so that appropriate boiler efficiency is achieved.

ENG File Template

General

This template describes the parameters known to be used by OR for defining a steam locomotive in the OR steam model.

This template is based upon the "standard" MSTS and MSTS_BIN ENG file.

The following colour code is used to describe the different parameters.

Black – not required or used by OR, so they could be left out.
Green – required for OR, these figures should be checked for accuracy of OR operation.
Red – Optional, **if value not known**, then leave parameter out.

ENG File

The following is an extract of the relevant sections of the ENG file that are related to the operation of the steam model. The values in this template are for demonstration only and relevant values should be sourced for the locomotive in question from a reliable source (see links above).

It is recommended that the units of measure should be the same as the source material that is used, as this will make data entry more accurate, and easier, as well as allow easier checking.

++++++++++++ Start of ENG File Extract Template ++++++++++++

```
Comment ( *** Boiler *** )
   BoilerLength ( 4.19m )
   BoilerVolume ( "220*(ft^3)" )
   ORTSEvaporationArea ( "2198*(ft^2)"  )
   BoilerEffectivity ( 1.0 )
   BoilerResponsiveness ( 1.0 )
   MaxBoilerOutput ( 30000lb/h )
   ExhaustLimit ( 21827lb/h )
   MaxBoilerPressure ( 160psi )
   SafetyValvesSteamUsage ( 11200lb/h )
   SafetyValvePressureDifference( 5 )
   SuperHeater ( 1.0 )
   MaxSteamHeatingPressure( 80psi )
   MaxWaterMass ( 3977lb )
   MaxTenderWaterMass ( 36500lb )
   PrimingFactor ( 1 )
   SteamMinPrimingLevel ( 1 )
   SteamPrimingPowerLossProportion  ( 1 )
   SteamPrimingWaterUsageIncreaseProportion  ( 1 )
   SteamPrimingReductionWithCylinderCocksOpen  ( 1 )
   SteamGaugeGlassHeight( 8 )

Comment ( *** Cylinders *** )
   NumCylinders          ( 2 )
   CylinderStroke        ( 26in  )
   CylinderDiameter      ( 21in )
```

CylinderVolume ("20.85*(ft^3)")
CylinderEffectivity (1.57)
CylinderCocksPowerEfficiency (0.9)
SteamCylinderCocksOperation (Manual) ??
BasicSteamUsage (1000lb/h)

Comment (*** Fire ***)
ORTSFuelCalorific (13700btu/lb)
ORTSGrateArea ("29.75*(ft^2)")
MaxFireMass (893lb)
IdealFireMass (595lb)
DraftingEffect (1.04)
BlastExponent (0.5)
SteamBlowerEffectExponent(0.9)
SteamBlowerEfficiencyExponent(1.1)
SteamBlowerMaxSteamUsageRate(500lb/h)
SteamBlowerMaxProportionOfBlastEffect(0.15)
ShovelCoalMass (10lb)
SteamFiremanMaxPossibleFiringRate(4200lb/h)
ORTSSteamFiremanMaxPossibleFiringRate(4200lb/h)
MaxTenderCoalMass (13440lb)
SteamFiremanIsMechanicalStoker (1.0)
CoalBurnage (4.84lb/hp/h)
BasicCoalUsage (298lb/h)
SmokeCombustion (1)
SteamSmokeUnitsPerPoundOfFuel(10)
SteamMaxSmokeUnitsReleaseRate(14)

Comment (*** Injectors ***)
InjectorSizes (9mm 12mm)
InjectorTypes(0 1)
InjectorLimits1 (40psi 0.6 1)
InjectorLimits2 (40psi 0 1)
Injector1FeedrateMultiplierExhaust (1.15)
Injector1FeedrateMultiplierLive (0.6)
Injector2FeedrateMultiplierExhaust (1.15)
Injector2FeedrateMultiplierLive (0.6)
Injector1WaterValveVarience (0.25)
Injector2WaterValveVarience (0.25)

++++++++++++ End of ENG File Extract Template ++++++++++++