





2007 PRINCE OF WALES

Building Britain's Most Powerful Steam Locomotive

IMechE Glasgow

David Elliott

Director of Engineering

The P2 Steam Locomotive Company Limited



Building Britain's most powerful steam locomotive

Introduction

Our mission



*“To develop, build and operate an improved
Gresley class P2
Mikado steam
locomotive
for main line and
preserved railway use”*

Introduction



Why build a new P2?

- To realise the potential of the original Gresley design
- The most powerful express passenger steam locomotives to operate in the UK
- All rebuilt as Pacifics in 1943/44 and scrapped by 1961
- Fills one of the most significant gaps in preserved steam
- The “procession to the plinth” continues
- We had so much fun building Tornado!

Introduction



A P2 in the 21st century

- Powerful locomotive capable of running on large part of the national network
- Increased haulage capacity – Perth to Inverness
Exeter to Plymouth
- Similar outputs to *Tornado* – 110+miles between water stops
- 75mph but potential for slightly higher

Why were the P2s built?



More power required



Gresley class A3 – final deliveries in 1934



Class C10/11
NB Atlantics –
double heading
frequent
Edinburgh to
Aberdeen

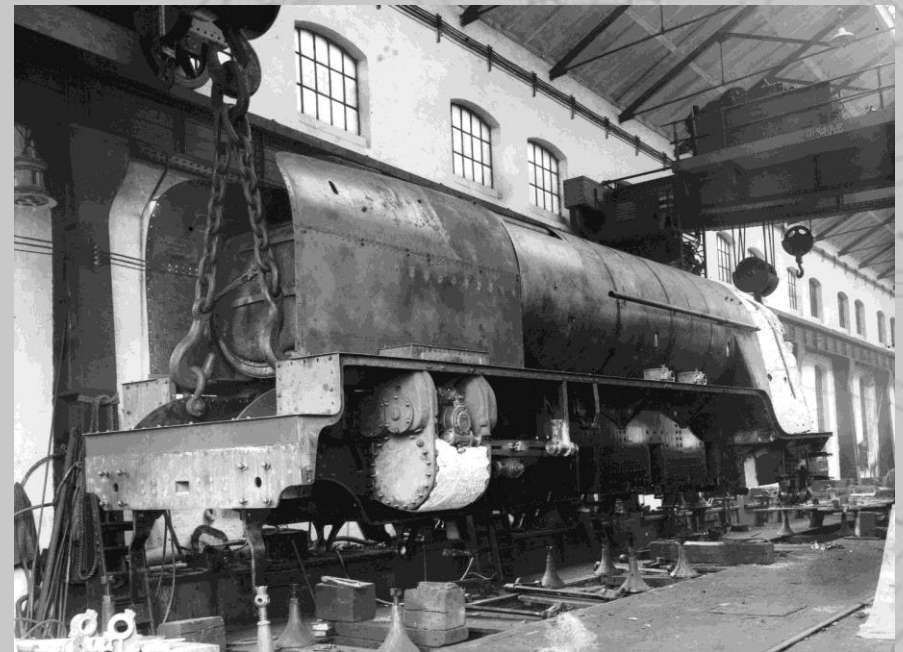


Gresley class P1 delivered in 1925 – 100 wagon trains

The building of the P2s



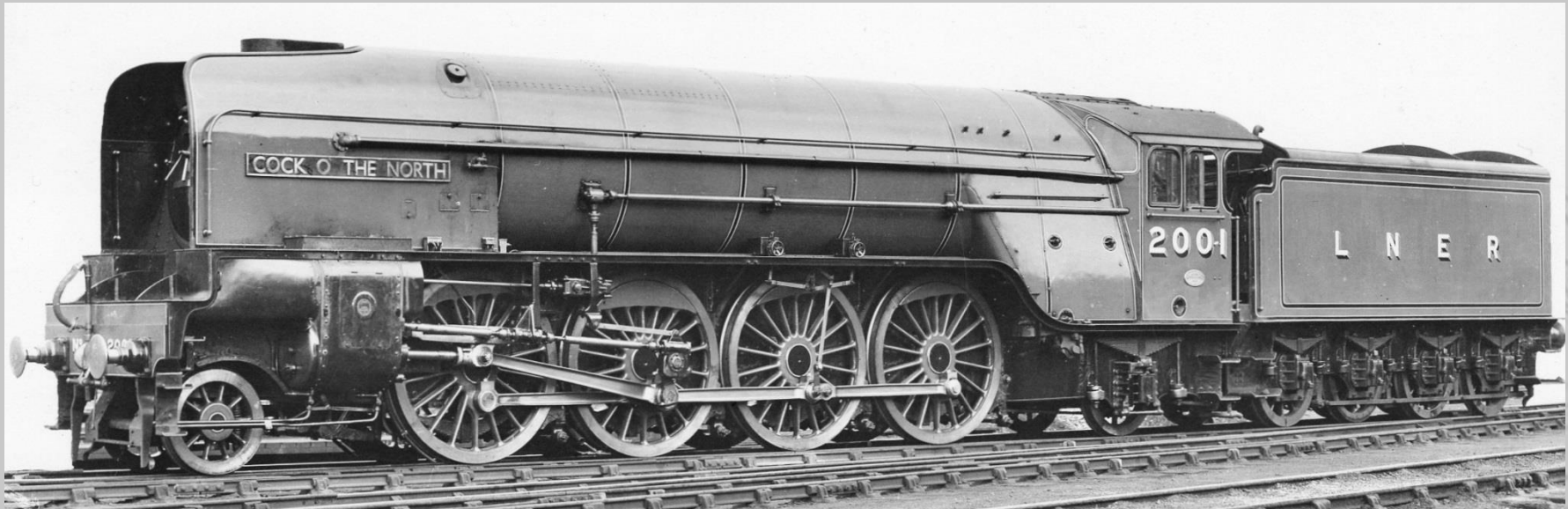
No. 2001 *Cock O'The North* under construction in 1934



The building of the P2s



The finished article, May 1934



- 2-8-2 Mikado wheel arrangement
- 50 sq ft firebox grate
- Kylchap chimney/blastpipe arrangement
- ACFI feed water heater
- Chime whistle
- Lentz rotary cam poppet valve gear
- Semi-streamlined and a V-shaped cab front
- All-welded tender with spoked wheels
- Gill Sans nameplate

The building of the P2s

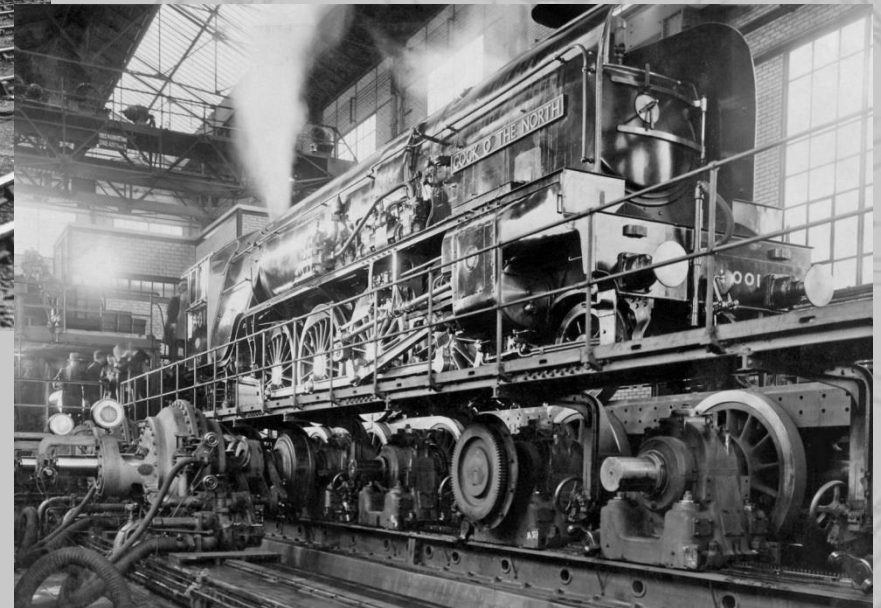


Cock O' The North unveiled to the press



The building of the P2s

No. 2001 on test



At Vitry-sur-Seine near Paris, France

The building of the P2s



'Giant locomotive' a celebrity during the 1930s

"COCK O' THE NORTH" IN CHOCOLATE.

A chocolate model of the L.N.E.R. Company's latest super-locomotive, "Cock o' the North," has been placed in the shop window at 68 High Street, Dundee, of James Keiller & Son, Ltd.

Nearly four feet in length, the model is made exactly to scale, and reproduces faithfully the huge boiler and diminutive funnel of the engine. An engine-driver dressed as Santa Claus is peeping from the cabin, while the tender is packed with chocolates instead of coals.



Cock O'The North was the only LNER locomotive to have a Spitfire named after during WWII



The building of the P2s



No. 2002 *Earl Marischal* – the 'conventional' sister –October 1934



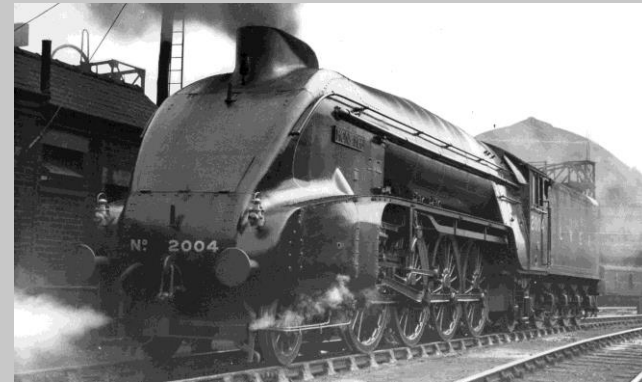
The building of the P2s



And then came the streamliners – June to September 1936



No. 2003 *Lord President* - first of the streamliners



No. 2004
Mons Meg
- bypass
valve to
divert
exhaust
from the
blastpipe



No. 2005 *Thane of Fife* - single
(non-Kylchap) chimney



No. 2006 *Wolf of Badenoch* - longer combustion
chamber in firebox to aid combustion
prototype for *Tornado's* boiler

The building of the P2s

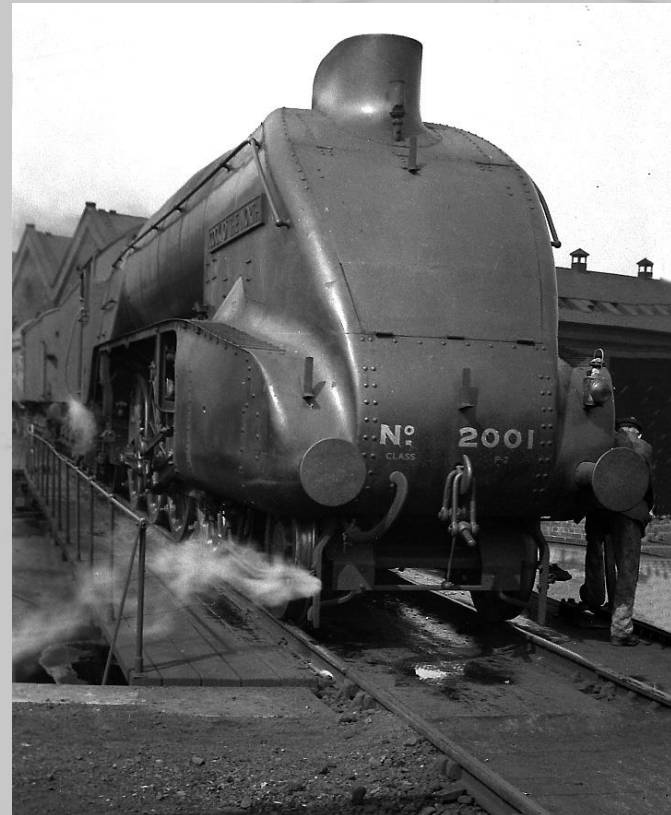


Nos. 2001/2 rebuilt as streamliners in 1936/7



No. 2001 was similarly treated in September 1937 with the ACFI feed water heater removed and its poppet valves replaced with Walschaerts/Gresley valve gear

No. 2002 entered Doncaster Works in October 1936 for its first heavy repair and also received a streamlined front end



The demise of the P2s



Thompson's ungainly rebuild



History of the Gresley class P2s



On-going research

15 DÉCEMBRE 1934

L'ILLUSTRATION

N° 4369 — 557

mètres. Selon l'expression courante, elle tournerait « folle », jusqu'à ce que ses pièces, arrivées à la limite de la résistance mécanique, cessent.

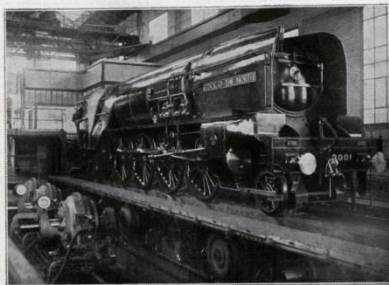
Par contre, si les roulements sont fermés, les roues motrices, prenant appui sur eux, exercent un effort de traction, effort limité par les dynamomètres. Dès lors, en faisant varier le freinage des roulements, il est possible de régler la vitesse et d'opérer en réglage avec des admissions de vapeur déterminées. Ainsi les conditions de l'expérience peuvent-elles être infiniment renouvelées.

Mais une difficulté était à vaincre, celle du



Le dynamomètre auquel est attachée la locomotive. Cet appareil permet d'apprécier des efforts allant jusqu'à 45 tonnes.

maintien de la constance de la vitesse. Cette dernière dépendait du freinage des roulements, il était nécessaire d'obtenir un freinage parfaitement régulier et demeurant égal à lui-même par rapport à toutes les variations, même les



La machine prête à faire ses essais sur le banc de Vitry-sur-Seine. Ses roues motrices et ses roues porteuses reposent sur les rouleaux. A gauche, sous des freins hydrauliques.

plus imprévisibles, d'allure de la locomotive.

Pour si malaisé qu'il soit, ce problème a cependant été résolu grâce à l'adoption d'un ensemble de dispositifs bien choisis, en particulier de freins hydrauliques d'origine et de fabrication anglaises.

Un nombre de six freins de chaque côté de la plate-forme servant d'assise, ces freins sont accouplés à six paires de roulements. Par conséquent, le banc est outillé pour profiter aux essais de machines à vapeur comportant six moteurs.

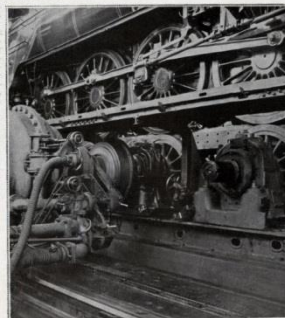
Mais l'éventail a été prodigieusement élargi. C'est ainsi que la plate-forme actuelle, d'une longueur de 24 mètres, pourra être allongée de 8 mètres, permettant ainsi la mise en place de nouveaux roulements et de nouveaux freins, si les besoins s'en font un jour sentir.

Déjà, même sans que fonctionne la station d'essai de Vitry, quatre locomotives, dont une Diesel électrique du P.-L.-M., ont été mises au

banc. Aucun incident n'a été relevé. Si ces machines avaient dû procéder à leurs essais en ligne, la dépense eût été beaucoup plus forte et le temps nécessaire beaucoup plus long.

Sur ce banc d'essai, qui est le plus moderne, le plus complet et le plus précis du monde, le « Cog du Nord » va procéder à ses essais au point fixe. Durant un mois, peut-être deux, essais se poursuivront. Certains de ces essais s'effectueront à très grande vitesse, 120 kilomètres à l'heure. Après quoi la même machine ayant utilisé notre installation s'en ira prendre son service régulier dans le pays d'Écouleuse. Et un nouveau témoignage du réalisme intelligent d'hommes lancés par le seul souci du progrès technique aura été obtenu.

Sur des appareils français munis de dispositifs français aura paru la démonstration de sa valeur. — R. C.



Détail des roulements sur lesquels repose la machine et des freins hydrauliques. Les roues motrices sont accouplées aux freins hydrauliques. Chaque frein peut absorber une puissance de 1.200 ch. La vitesse maximum à la jante des roues peut atteindre 100 km/h, et la charge supportée, 17 tonnes par roue.

UNE LOCOMOTIVE PROTOTYPE BRITANNIQUE VENUE FAIRE SES ESSAIS À LA STATION DE VITRY-SUR-SEINE

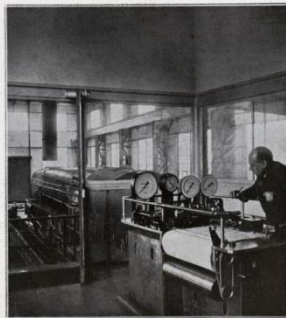
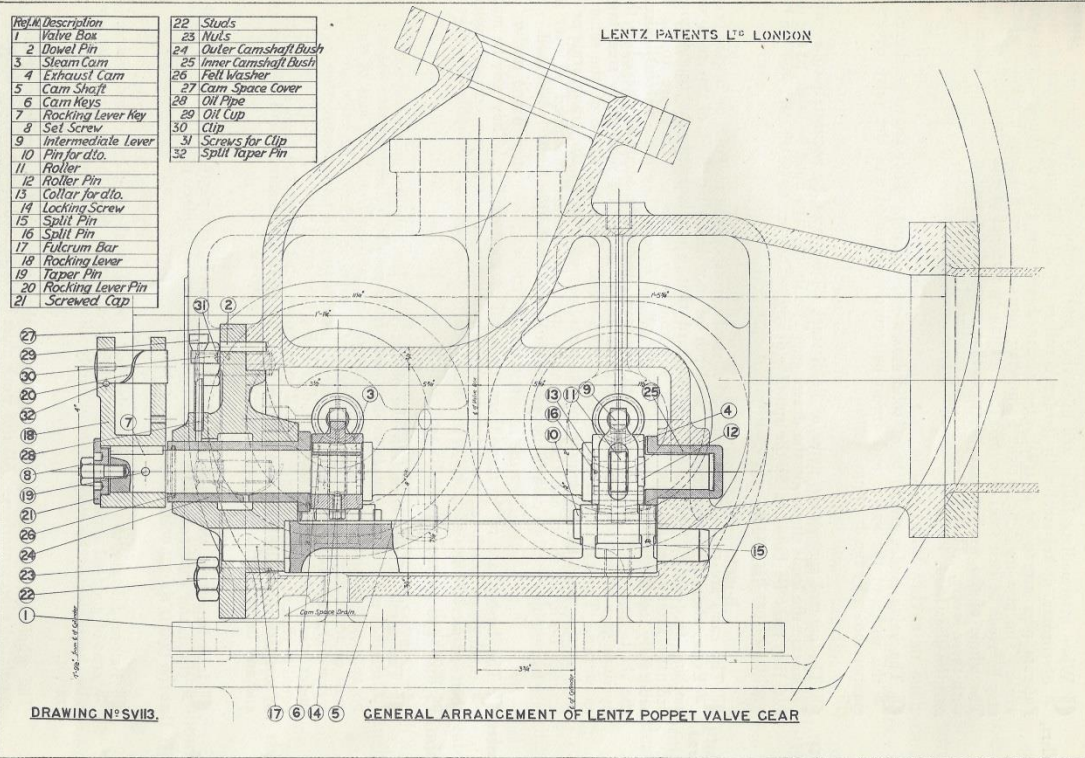


Table dynamométrique d'enregistrement de la vitesse, de l'effort de traction, de la puissance développée et du travail effectué. D'autres appareils permettent d'analyser le bilan thermique de la chaudière et le rendement électrique des moteurs. — Photographie J. Côté-Guyot.



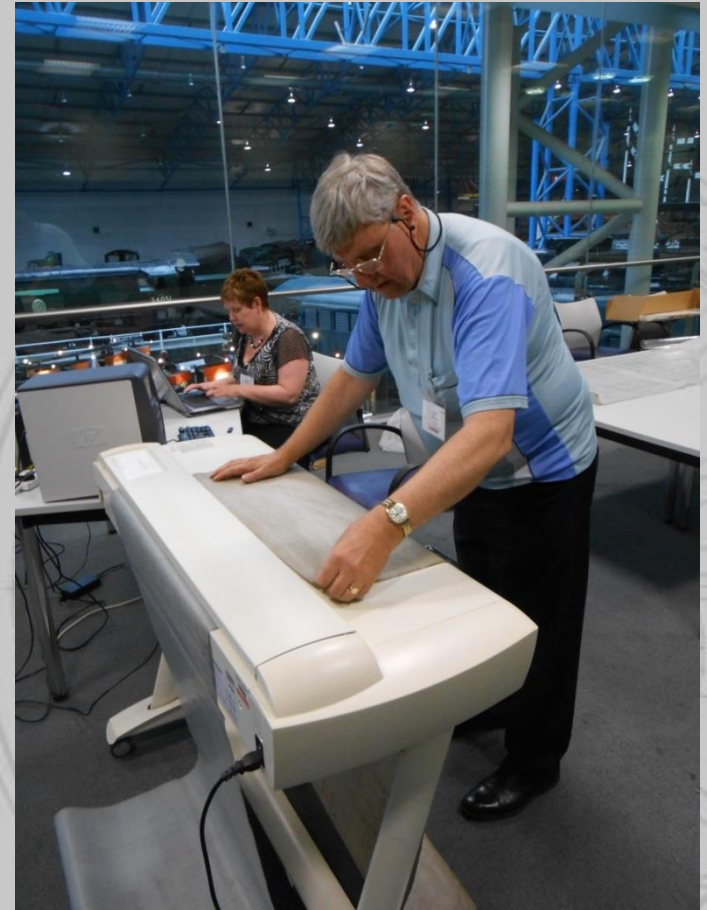
Creating No. 2007



It starts with the drawings...



Tony & Gill Lord scanning P2 drawings
at the NRM





Key design principles

- The final design will be aesthetically similar to P2 No. 2001 *Cock O' The North*. This is a construction and development project, not an opportunity for major redesign
- The design will make maximum use of systems, fittings and processes in use on A1 No. 60163 *Tornado*. Any changes to the original design will be either for operational, ease/cost of manufacturing or certification reasons
- The design must take into account the needs of the operator and customer. All decisions to be judged on value for money
- The design must meet current and foreseeable regulatory standards to allow the locomotive to operate as intended

Creating No. 2007



Key design principles cont'd

- Whole locomotive to be drawn in 3D CAD
- Existing design to be used except:
 - Alterations to alleviate known problems with original design
 - Changes required to meet modern operating requirements
 - Equivalent *Tornado* design can be used
 - Improvements to assist maintenance and life-cycle costs
- Materials at least equal to and preferably better than original
- Achievement of compliance with rail industry standards

Creating No. 2007



Timeline

Major components

2013 2014 2015 2016 2017 2018 2019 2020 2021

Detailed design work

Frames

Cylinders & valves

Smoke box & fittings

Boiler

Wheels

Motion

Pony truck & Cartazzi

Electricals

Tender

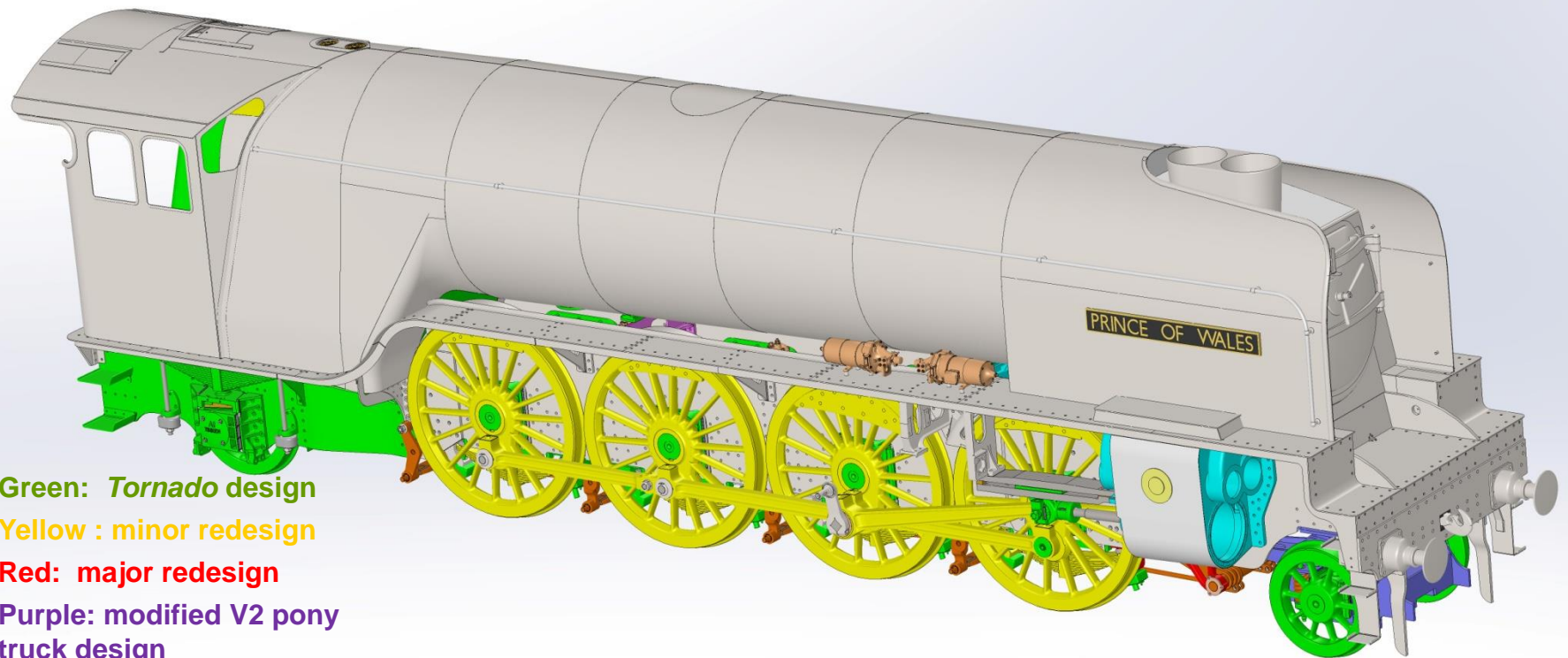
Fitting out

Trials & testing

Detailed design



Commonality with *Tornado* and new design

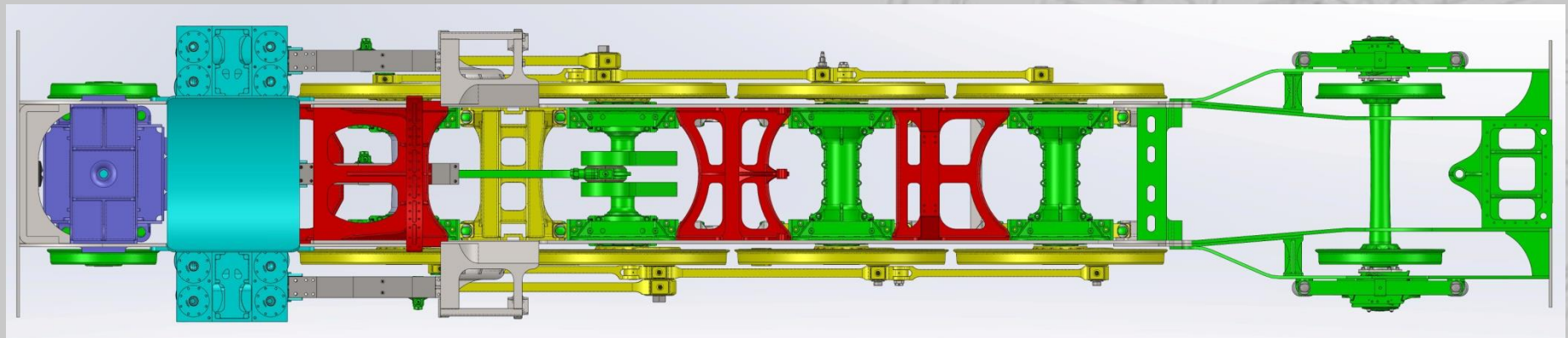
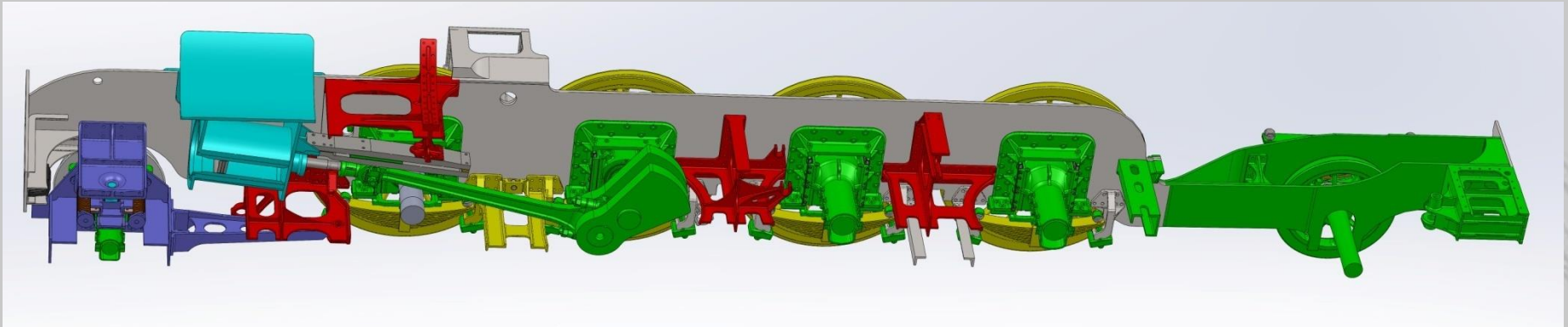


- Green: *Tornado* design
- Yellow : minor redesign
- Red: major redesign
- Purple: modified V2 pony truck design
- Blue: cylinders and valves

Detailed design



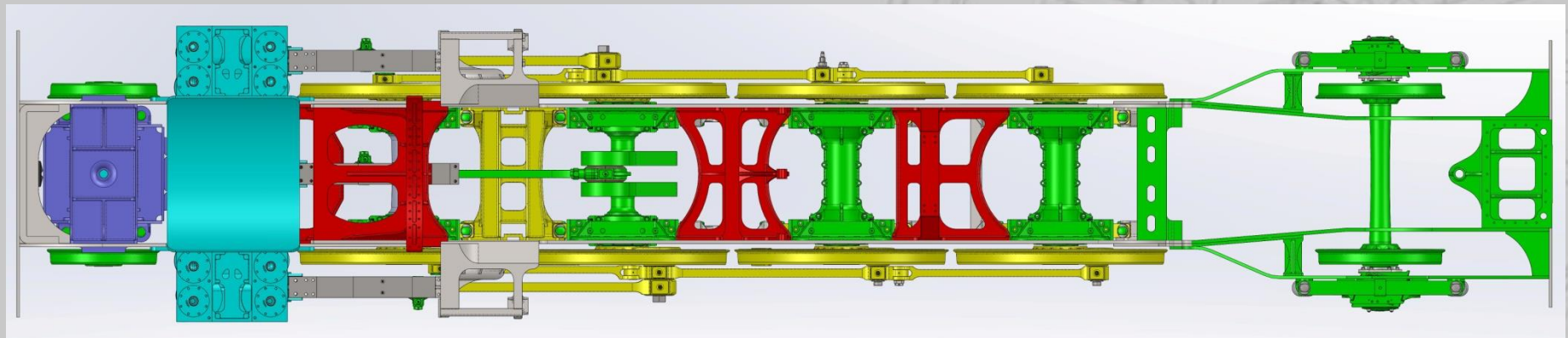
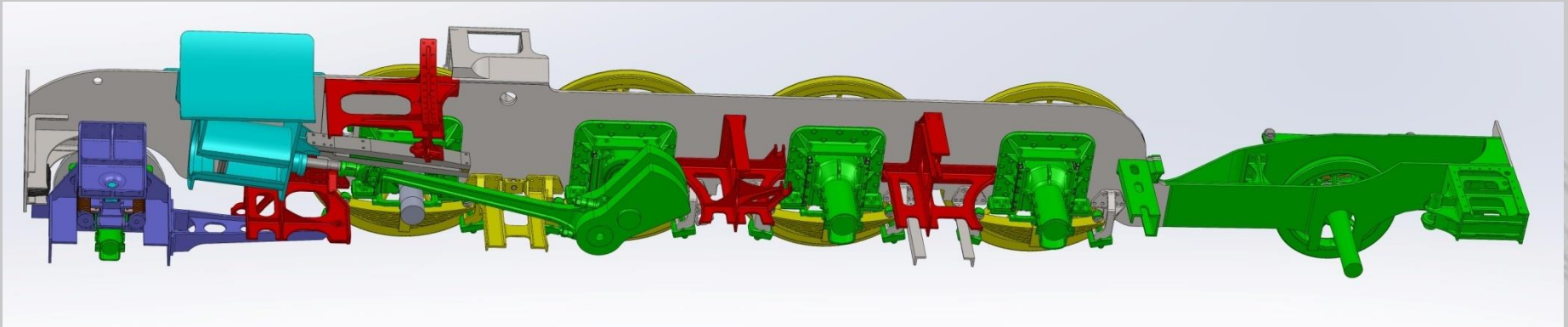
Some more views



Detailed design



Some more views



Construction starts



The first parts appear!



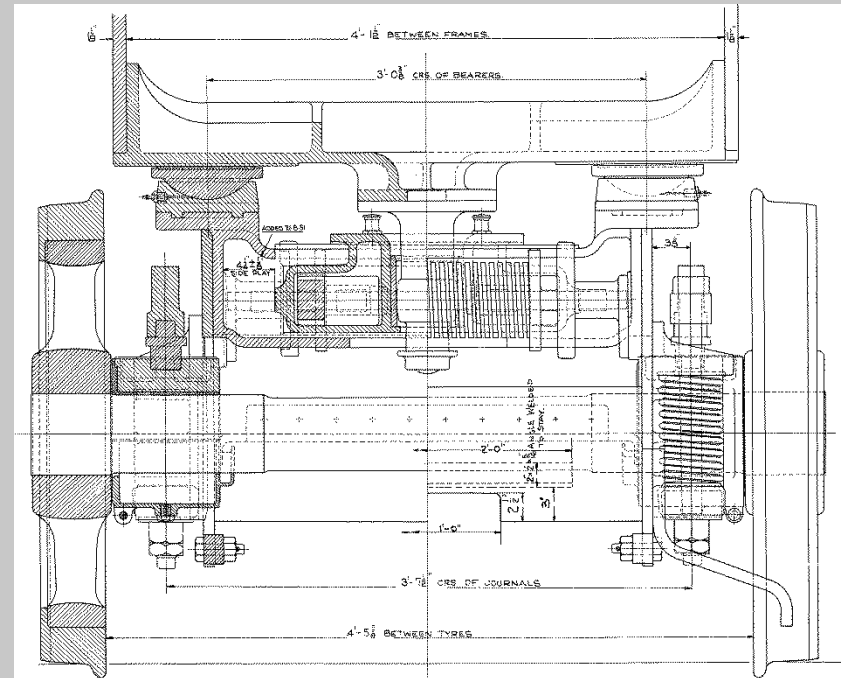
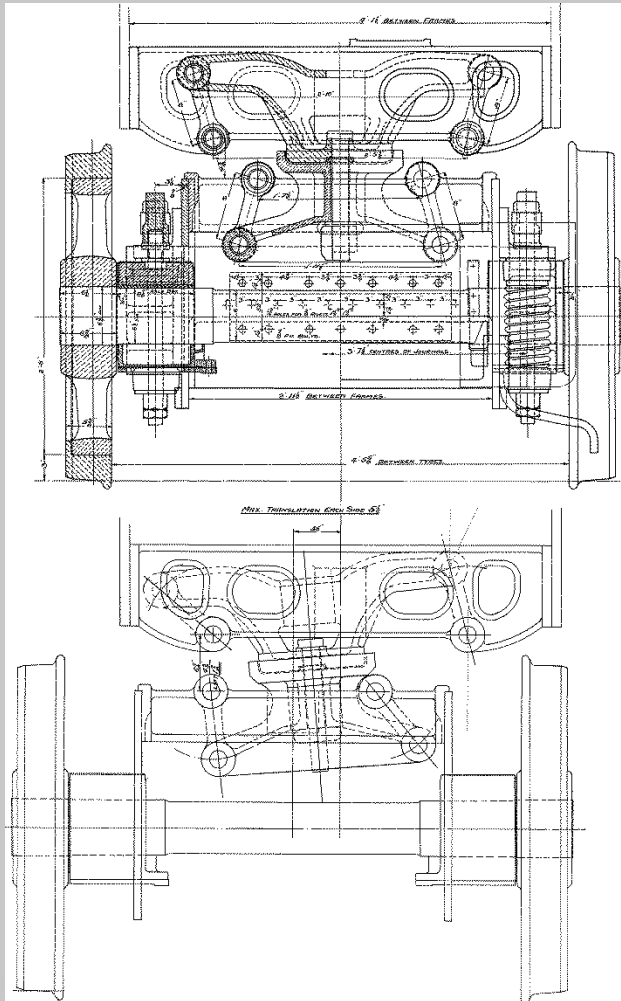
James May (from *Top Gear*) makes the first component – the smokebox dart – at Darlington on 20th February 2014



Detailed design



Pony truck



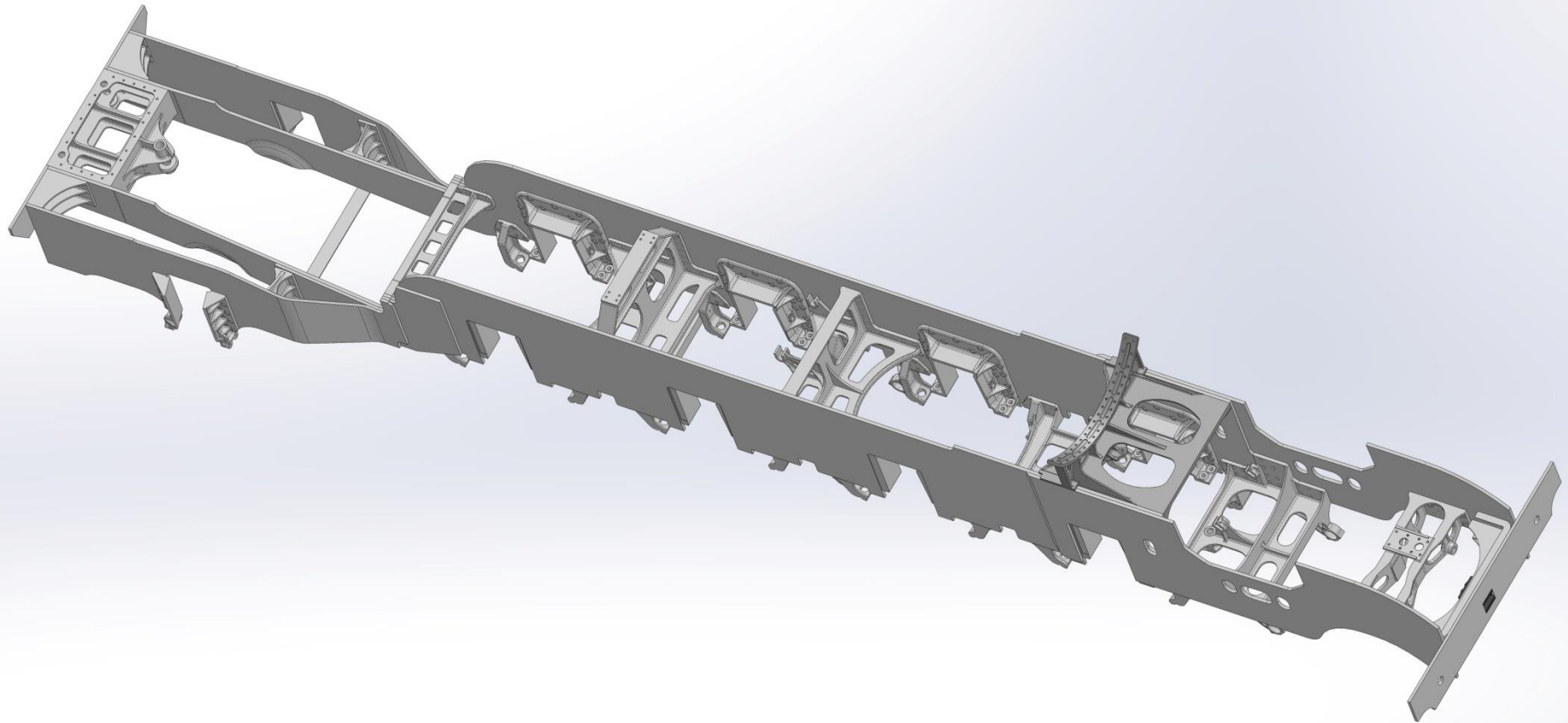
Post war V2 side control spring design

Original swing link design

Frames



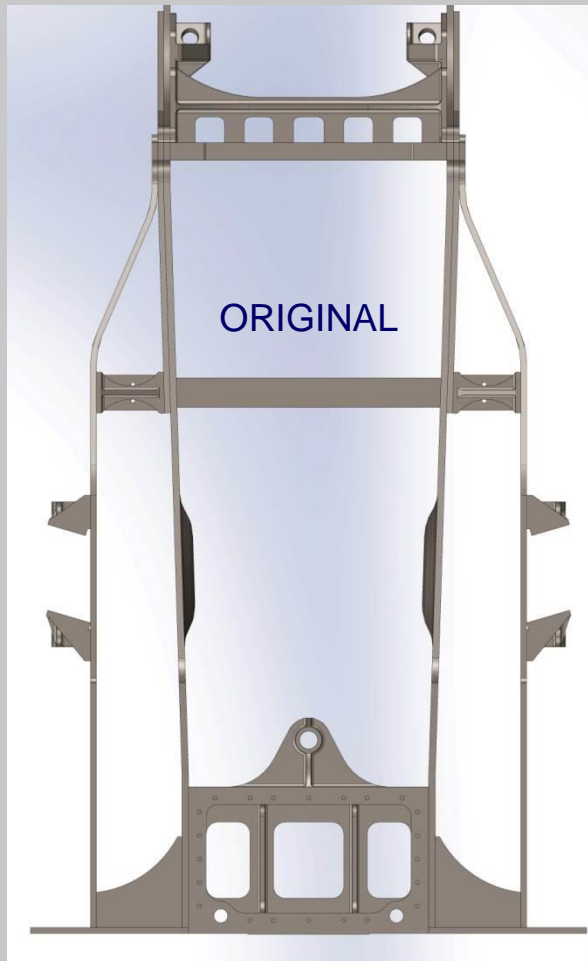
Frame design – original No. 2001



Frames

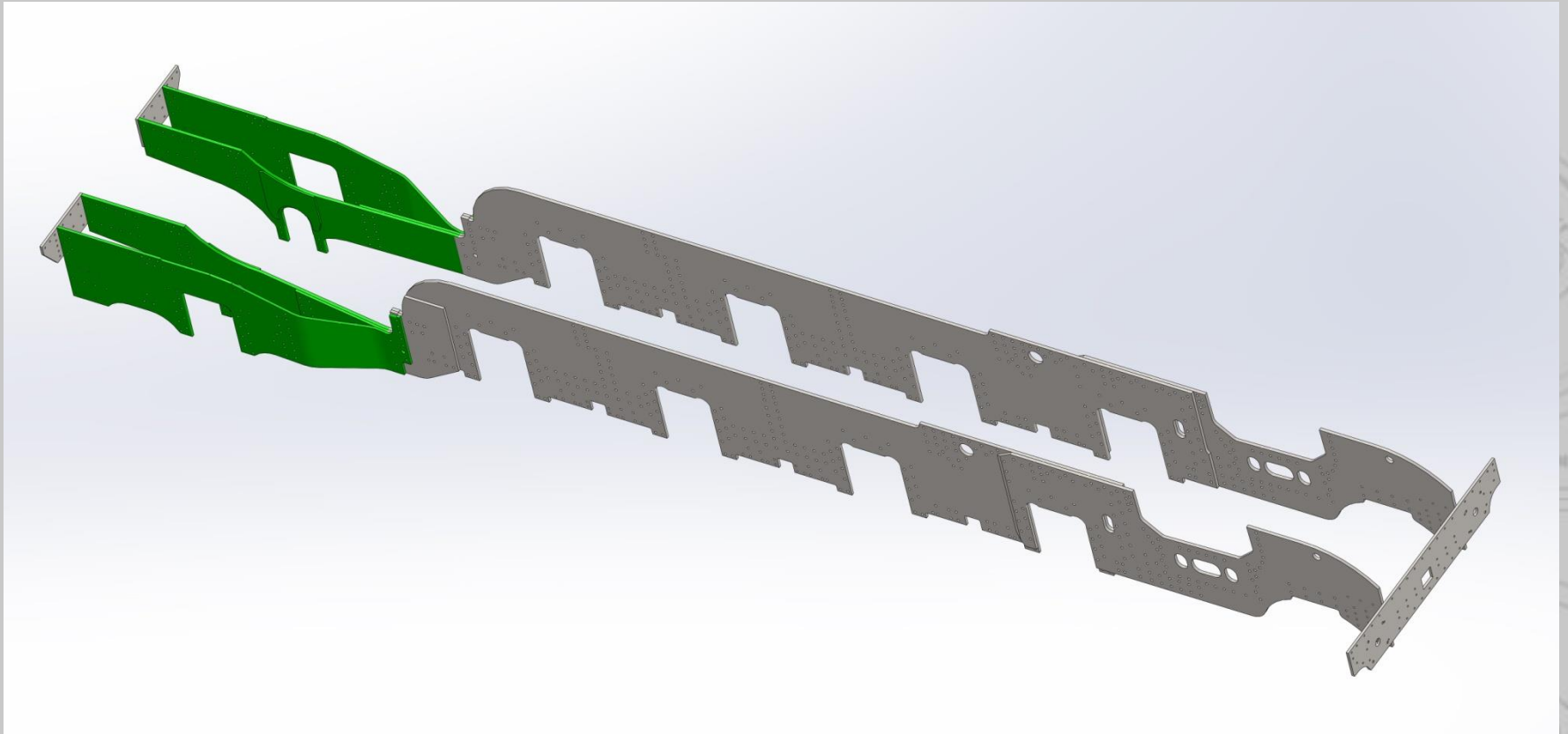


Frame design comparison – rear end



Frames

3D Model



- Frame plates – 3D model

Frames



The frame plate material is rolled 23rd April 2014

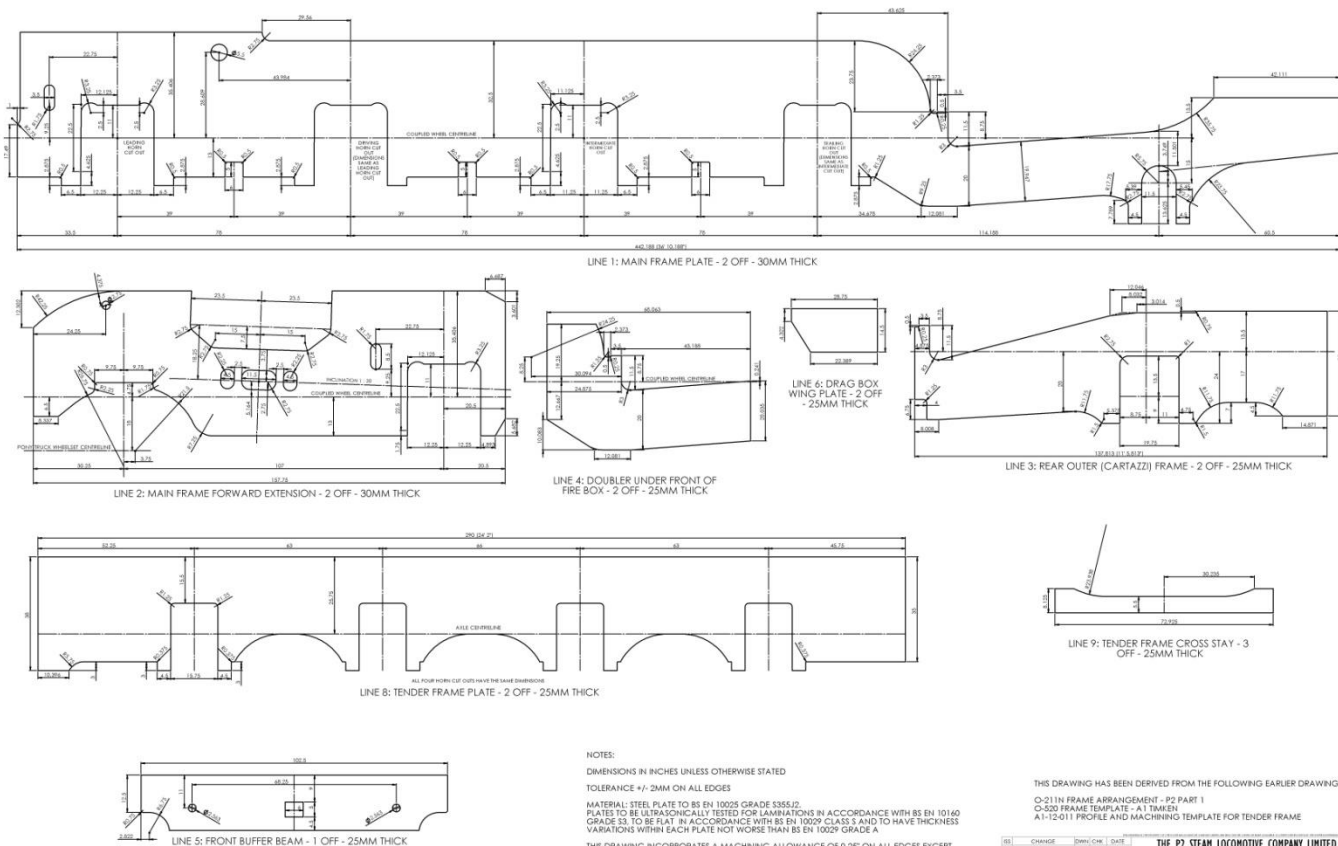


Frames

Profiling drawing



P2-01-001



NO.	CHANGE	DATE	BY	DATE	BY
1	NEW DRAWING	01/01/14	01/01/14	01/01/14	01/01/14

THE P2 STEAM LOCOMOTIVE COMPANY LIMITED					
FRAME PROFILES					
DRAWN BY:	DATE:	REF:	DATE:	DATE:	DATE:
01/01/14	01/01/14	01/01/14	01/01/14	01/01/14	01/01/14
CHECKED BY:	DATE:	REF:	DATE:	DATE:	DATE:
01/01/14	01/01/14	01/01/14	01/01/14	01/01/14	01/01/14
FROM LINEER DWD NO:	DATE:	REF:	DATE:	DATE:	DATE:
01/01/14	01/01/14	01/01/14	01/01/14	01/01/14	01/01/14

SCALE: 1:10

DRAWING NO: P2-01-001

Frames



Sir Nigel Gresley's grandsons start the profiling on 21st May 2014



Ben and Tim Godfrey start the profiler

Frames

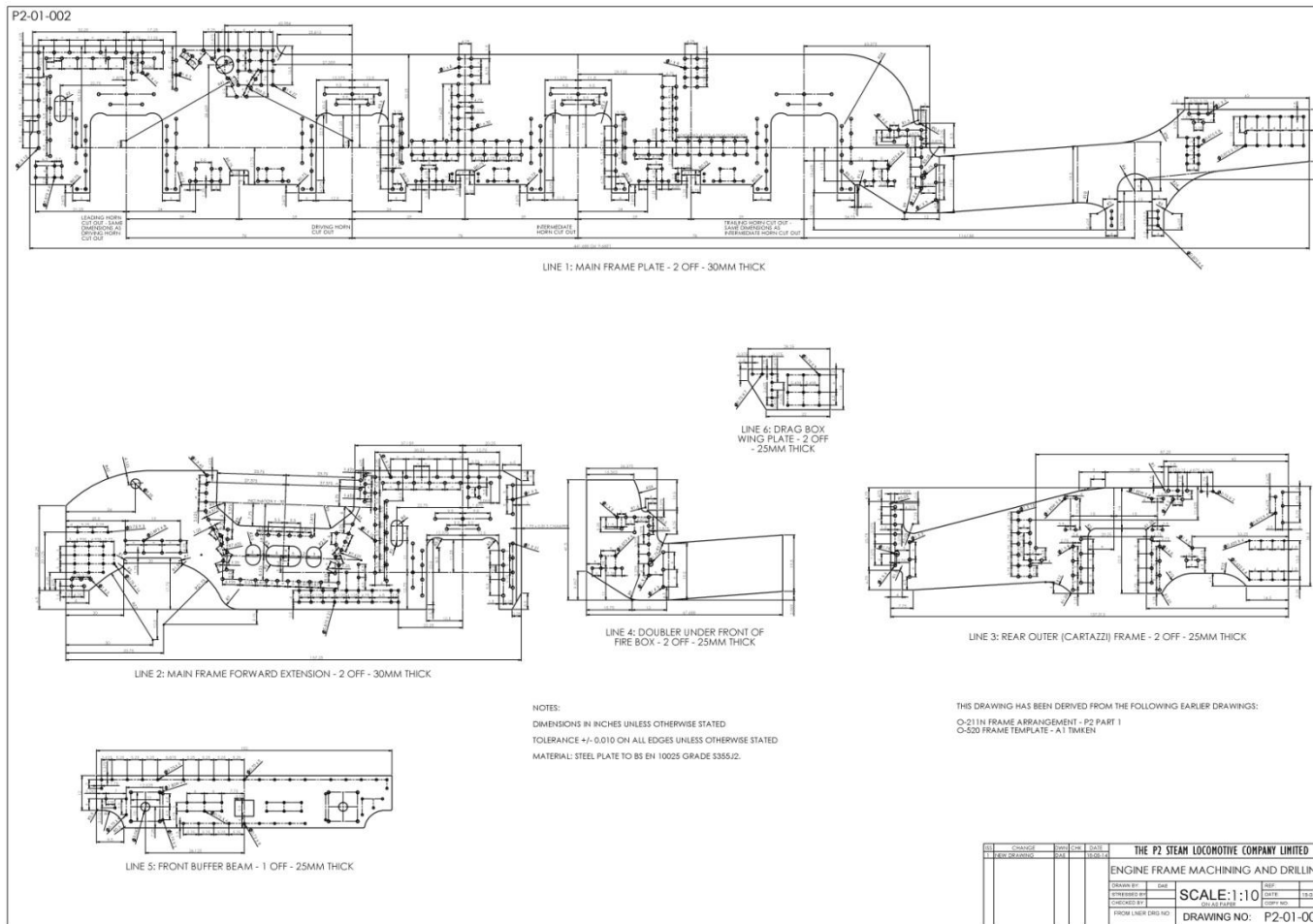


Darlington works is prepared for the new occupant



Frames

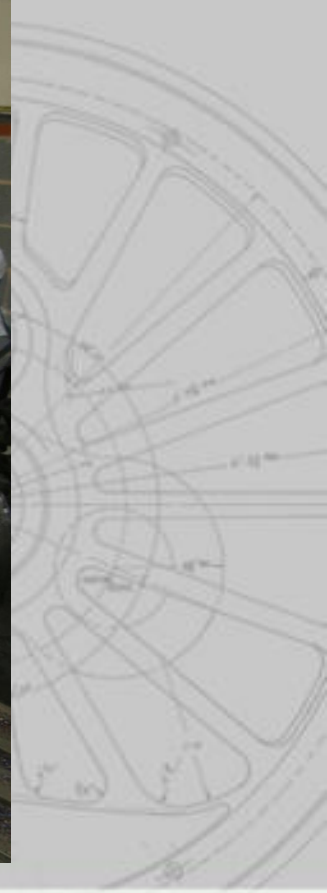
Machining and drilling drawing



Frames



Machining frame plates at Boro' Foundry



Frames



A flat pack kit arrives at Darlington...



Frames



....and assembly starts



Frames

The rear frame is heated and bent



Frames

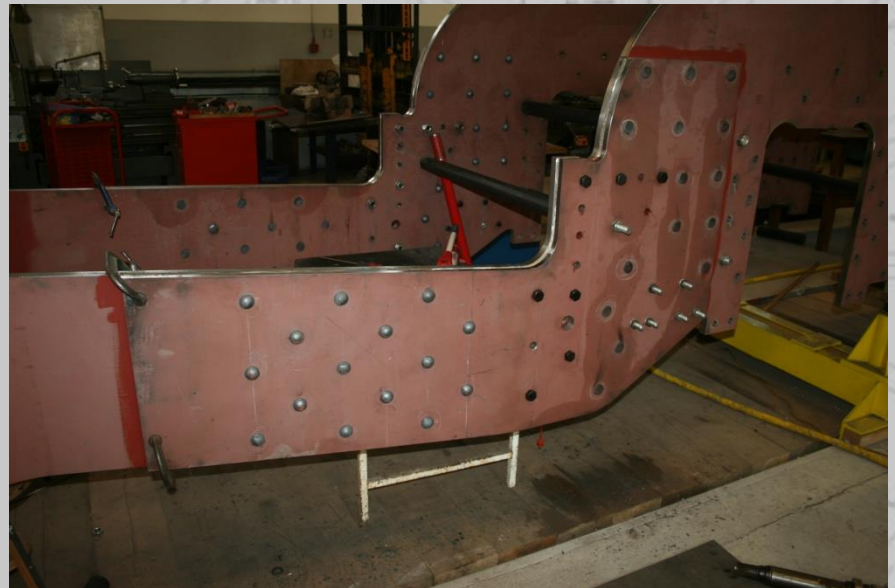


Mick Robinson surveys his handiwork



Frames

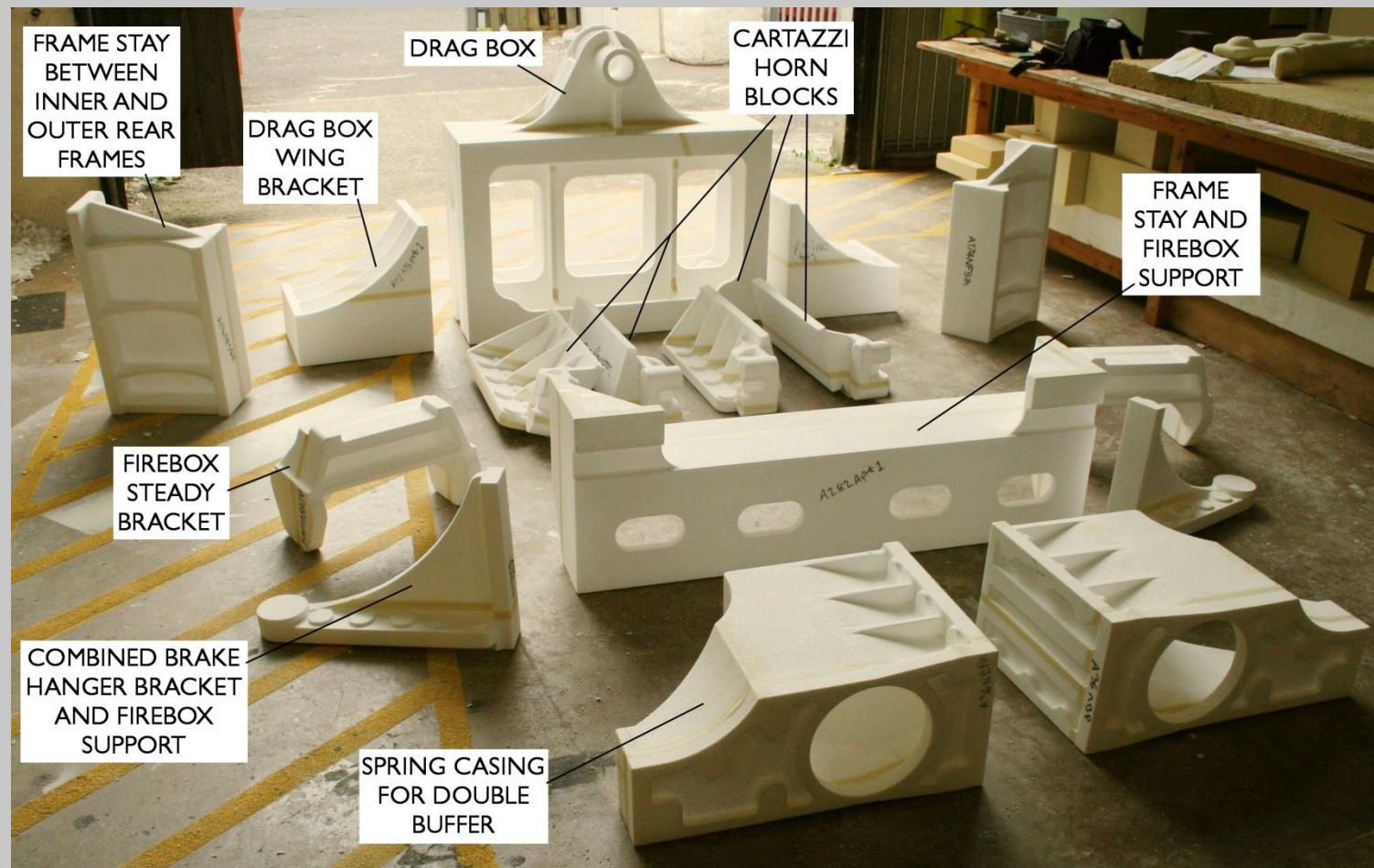
Doublers are riveted on



Frames



Polystyrene patterns for frame castings – castings completed



Frames and wheels

Some of the 66 castings made so far....



Frames



Tornado meets Prince of Wales!



Cylinders & valves



Cylinders

- P2 cylinders were 2in wider overall than A1 cylinders
- Modern track has reduced clearance between rails and platforms
- No. 2007 must be no wider than *Tornado* to retain route clearance
- 250psi boiler permits reduction in cylinder diameter to $19\frac{3}{4}$ in to maintain tractive effort
- Use of improved design will enable No. 2007 cylinders to be no wider than those on *Tornado*

Cylinders & valves



Valve gear

- No. 2001 was equipped with Lentz rotary cam poppet valve gear
- Originally with continuously variable cut-off
- Modified to stepped cams providing limited cut off settings following excessive wear on original cams
- Resulted in reduction in economy due to wide steps in cut-off and continued problems with high wear rate
- Investigations pointing to improved version of Lentz gear using the 1940s developments by Franklin in the USA
- Major design study will confirm selection

Cylinders and valves



Shortage of original P2 Lentz valve gear drawings

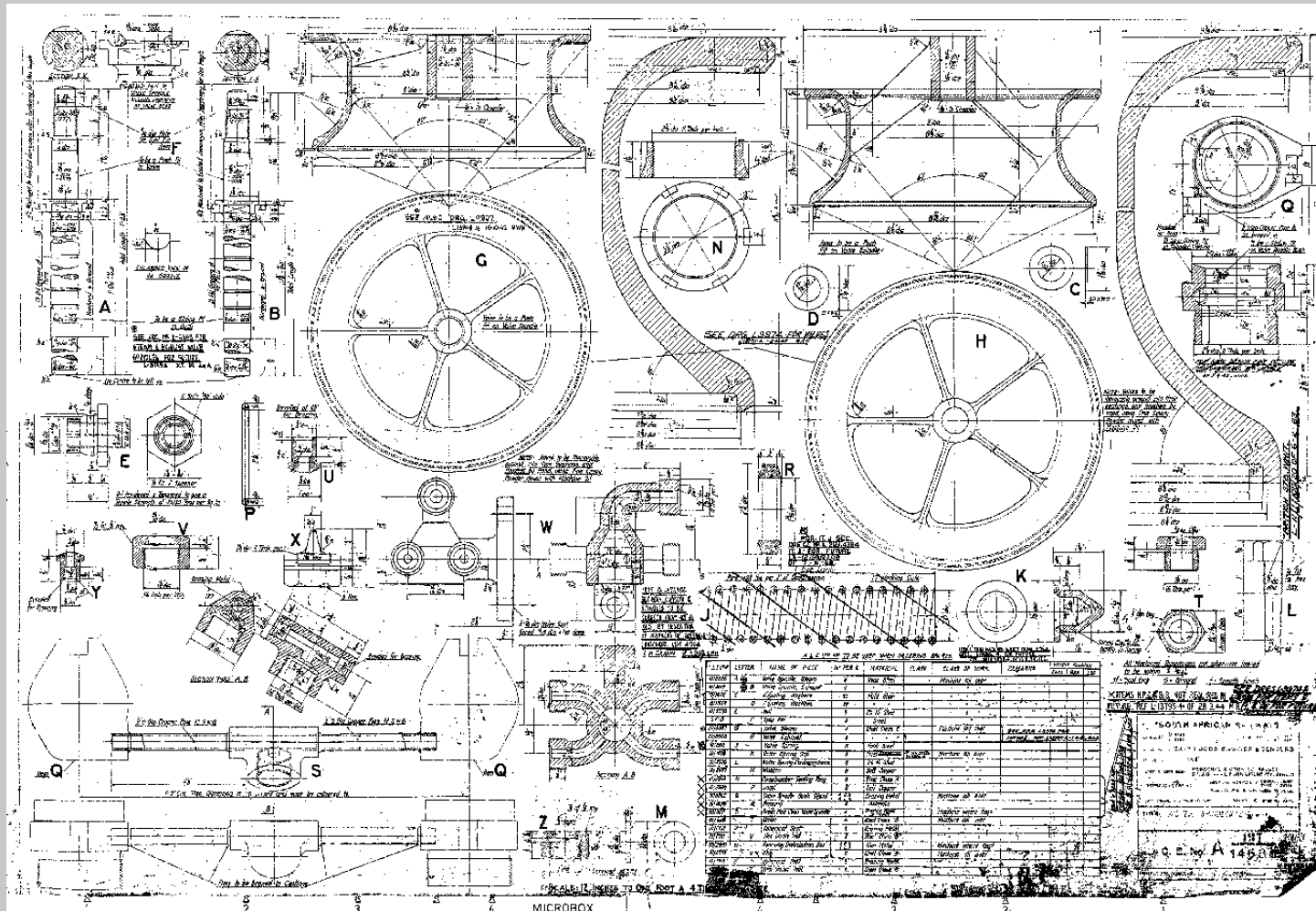


South African 15E class similar in size and built in 1934/5 with Lentz valves

Cylinders and valves



Copies obtained of 15E valve gear



Cylinders and valves



Franklin development of Lentz gear with infinitely variable cams



Cylinders and valves

Franklin drawings lent by Charles Smith

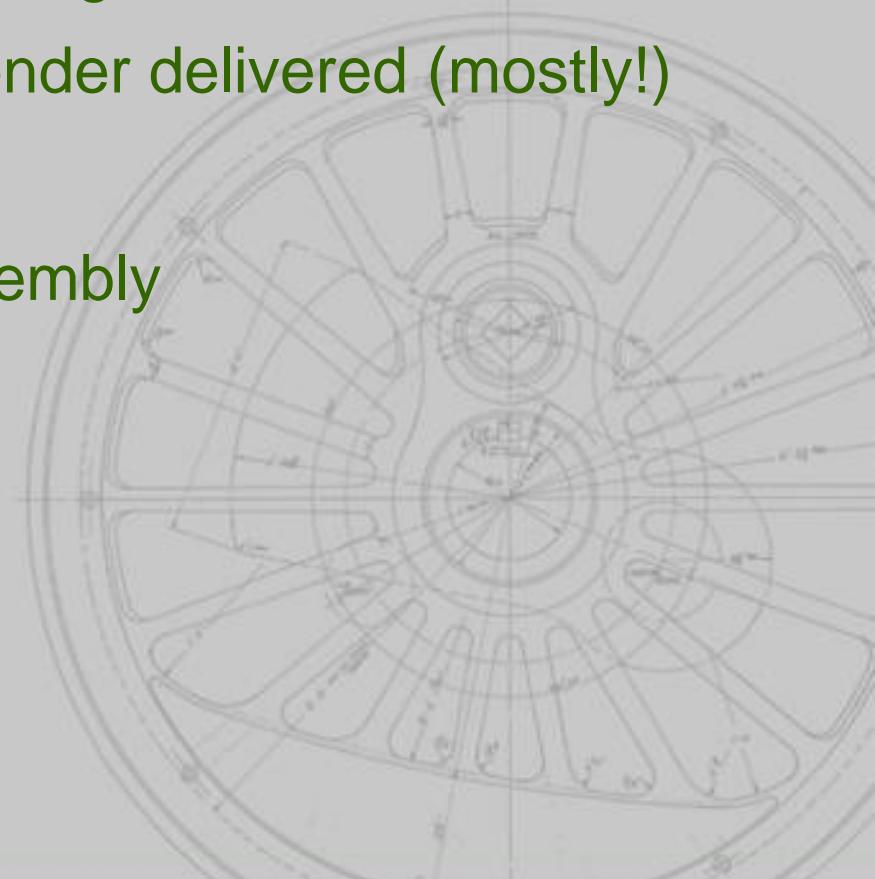


Wheelsets



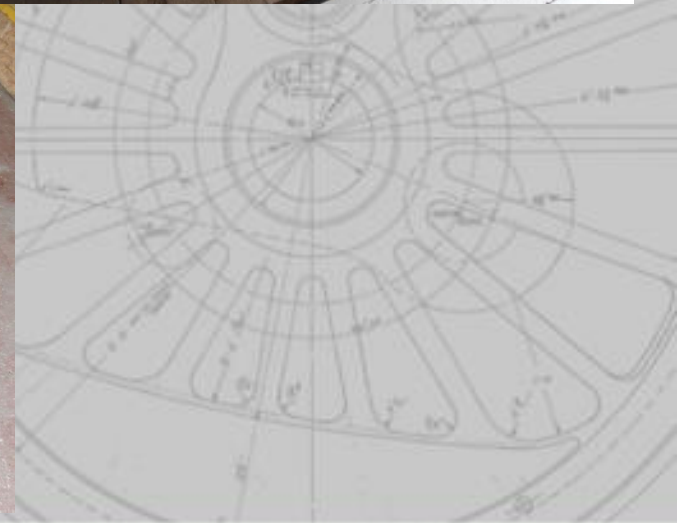
Wheels, axles and bearings

- All wheel castings completed for engine and tender
- Roller bearings for engine and tender delivered (mostly!)
- Tyres delivered
- Quotes sought for axles and assembly
- Axle and cannon boxes cast



Wheels

From 3D model to casting



Wheels

Final driving wheels are cast



Wheels

And proof machined...



Wheels



Engine tyres delivered



Wheels



Axle and cannon box castings



Wheels



A problem – crank axle failures



19(?) July 1939

P.2 class Engine No. 2005

Crank Axle - fractured through
journal & wheel seat,
creeping flaw.

Material : Steel

Makers : (Shafts & Webs) - Monkbridge
(Web Pin) - Vickers

Age : 2 yrs 11 mths.

Mileage : 133,000

Fracture occurred in Scotland
and reported by Mr. Heywood,
Mechanical Engineer,
Bowlaers.

Our papers G.208/130

Wheels



Crank axle failures

- At least 5 crank axle failures in a class of 6 locomotives over a maximum of 10 years
- 2 likely causes
 - High starting torques – max piston force approx 34 tons compared with similarly equipped A3 class with max piston force of 30 tons
 - 8 coupled wheels reducing tendency to slip in high torque conditions
 - Sub-optimal design

Wheels



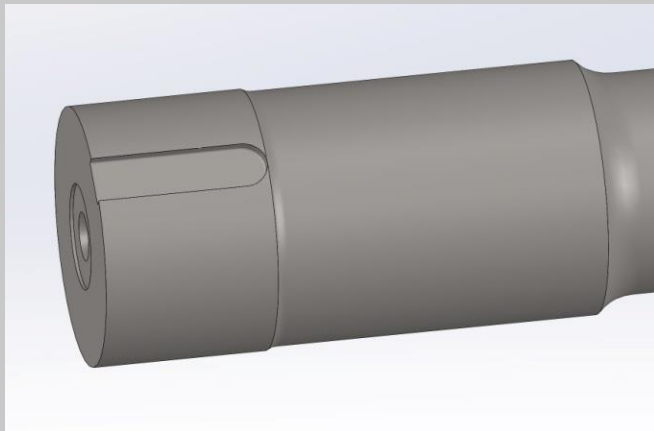
Solutions

- Use Timken A1 crank axle design modified to incorporate BR BASS504 design criteria
- If insufficient, increase diameter of axle in bearings from 9.625" to 10" – Timken bearings available with larger bore that will fit in existing axleboxes.
- Target fatigue life in excess of 250,000 miles at which point following LNER practice, crank axle will be renewed

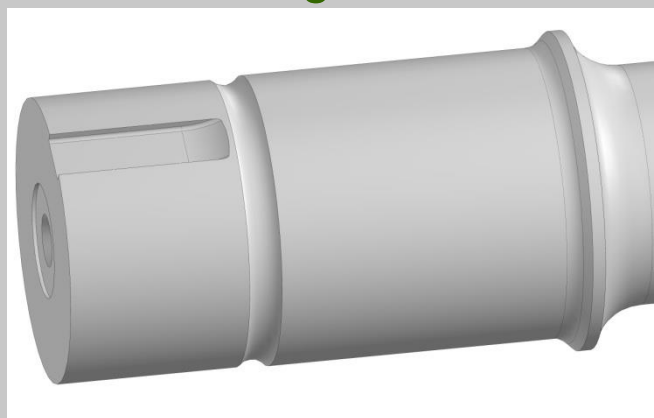
Wheels



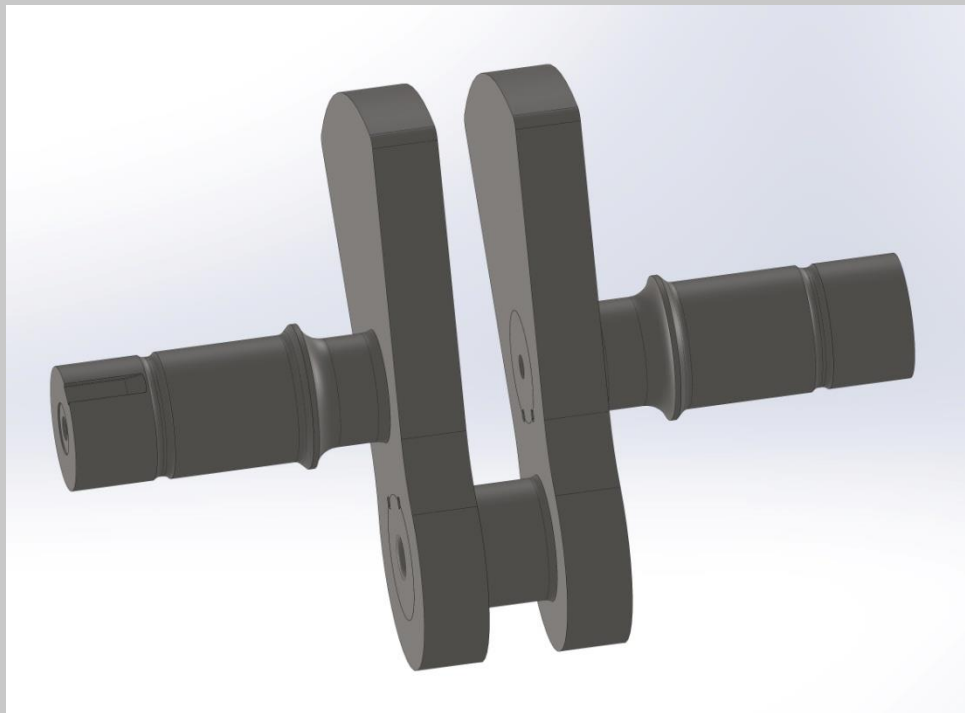
Solutions



Original



10" bearing seat with BASS504



Timken A1 design with BASS504

Boiler



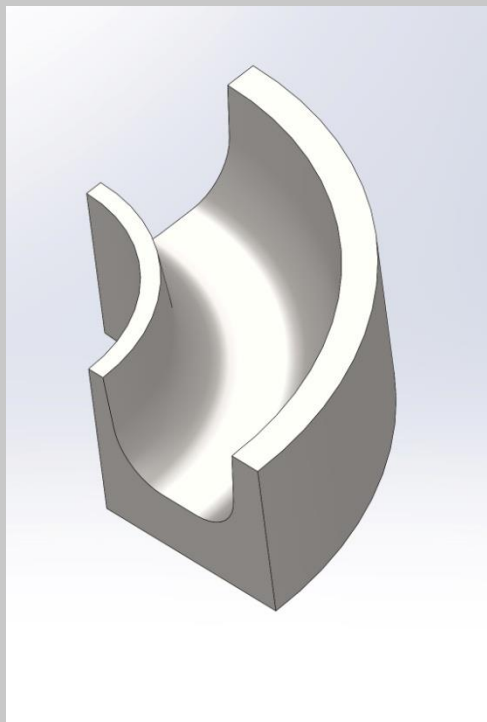
Boiler design

- Use of diagram 118A *Tornado* boiler with detailed modifications to improve overhaul life
- Interchangeable with *Tornado* boiler
- *Tornado* boiler is 17in shorter than P2 boiler – smoke box will be extended within cladding
- 250psi retained to improve economy and increase maximum power

Boiler

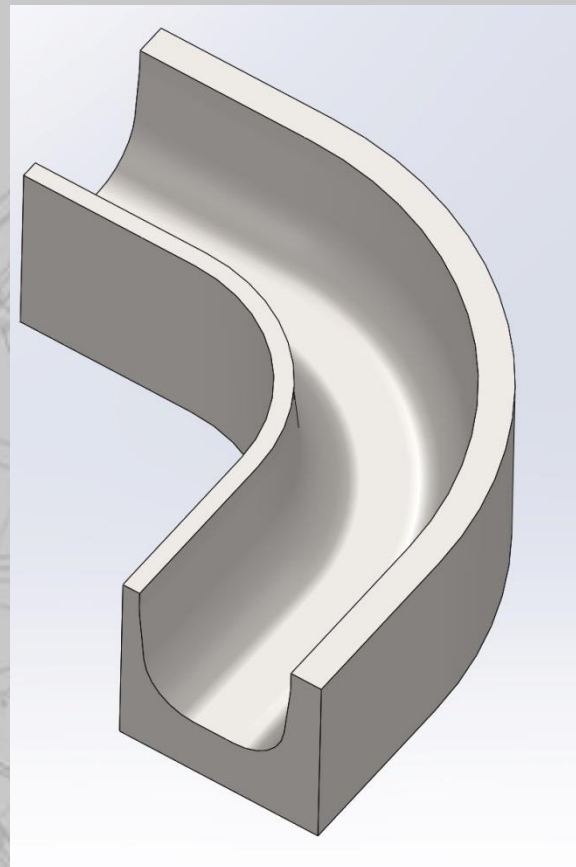


Boiler life improvement - forged foundation ring corners



← Original design
machined from
solid plate

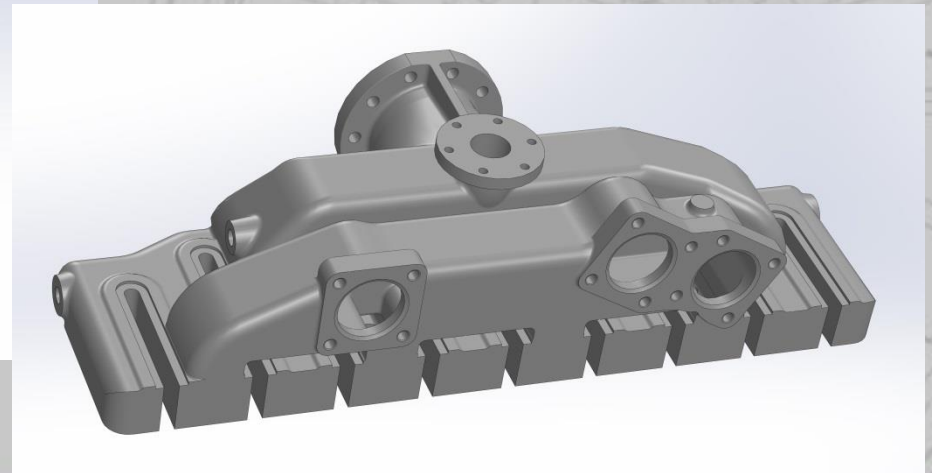
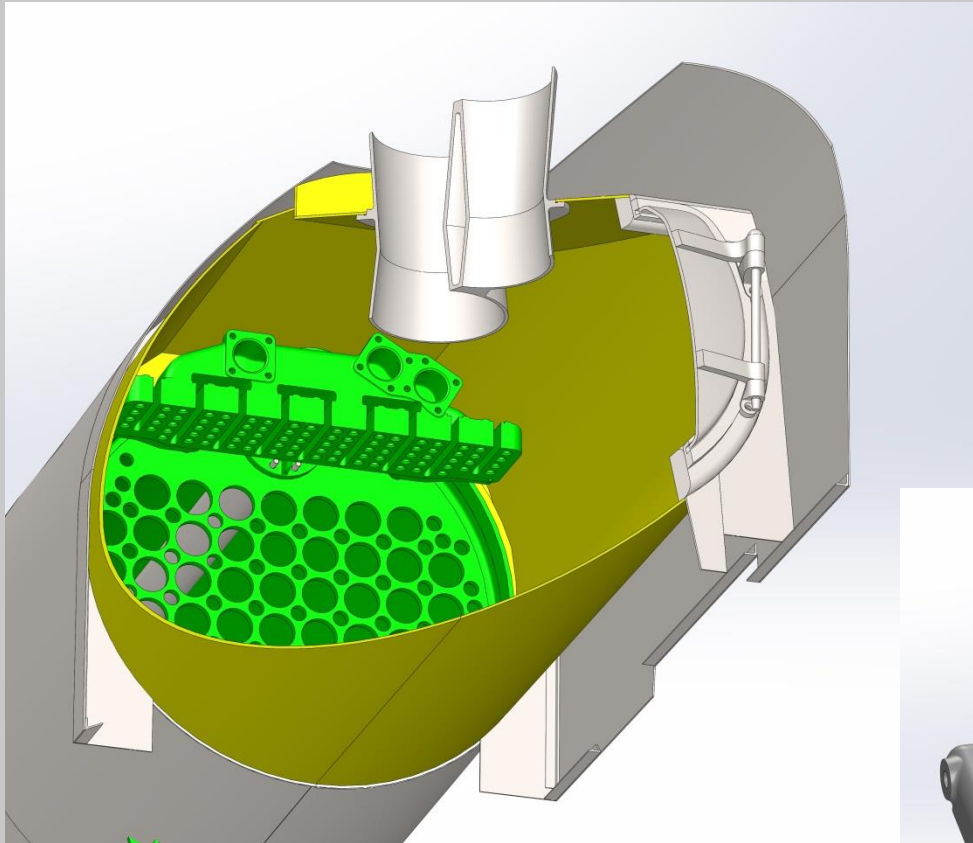
New design as
forging with
extended ends and
height to facilitate
replacement on
existing boiler



Boiler



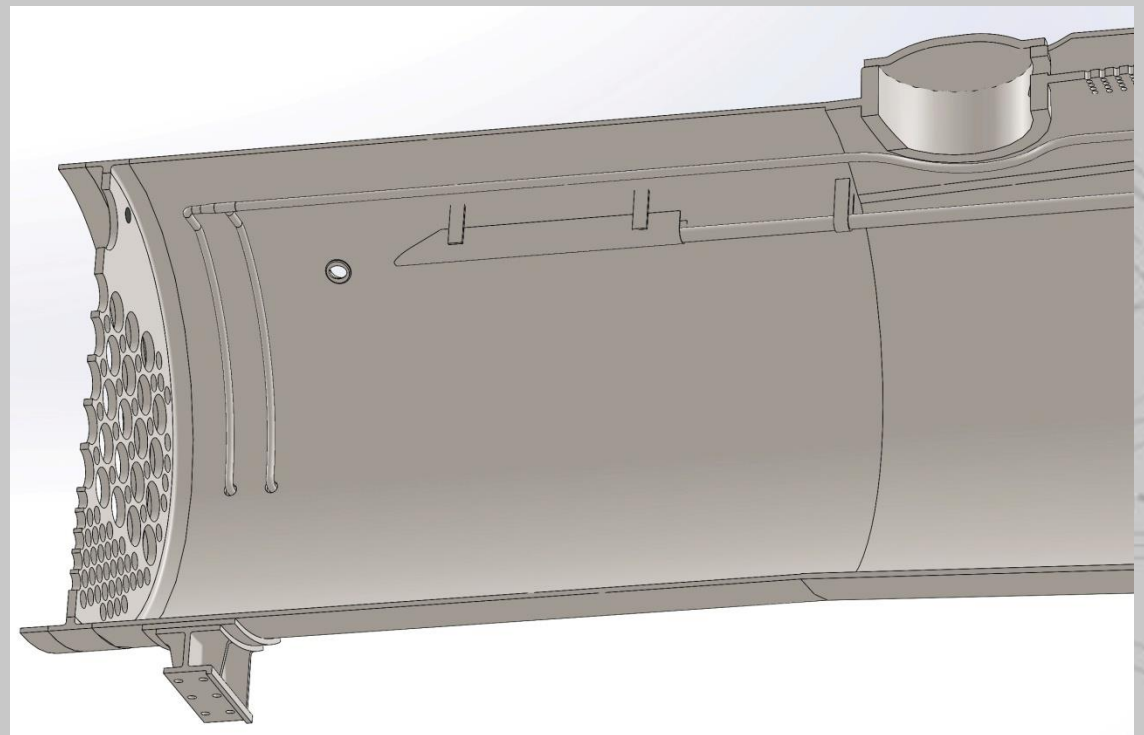
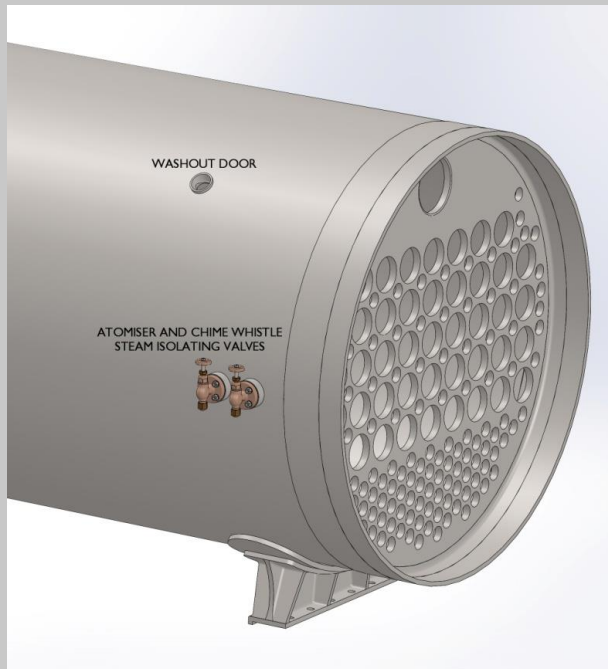
Model of *Tornado's* superheater header to check that it fits –it does!



Boiler



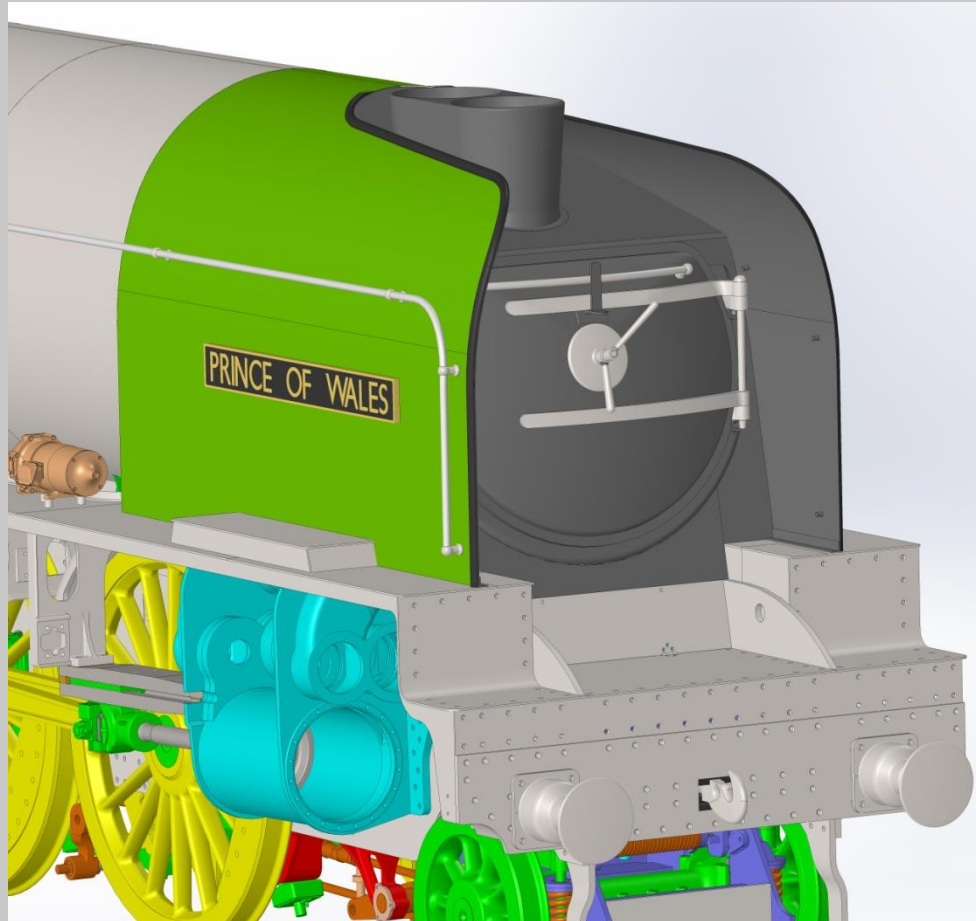
Re-routing of steam pipes to atomiser and whistle



Smokebox



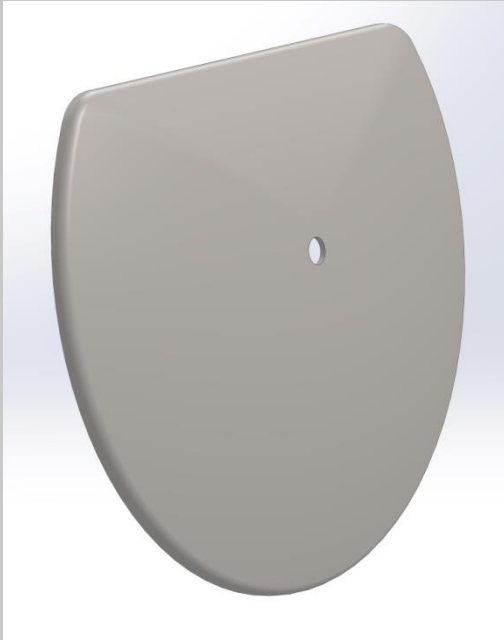
Smokebox being sponsored by the Gresley Society



Smokebox

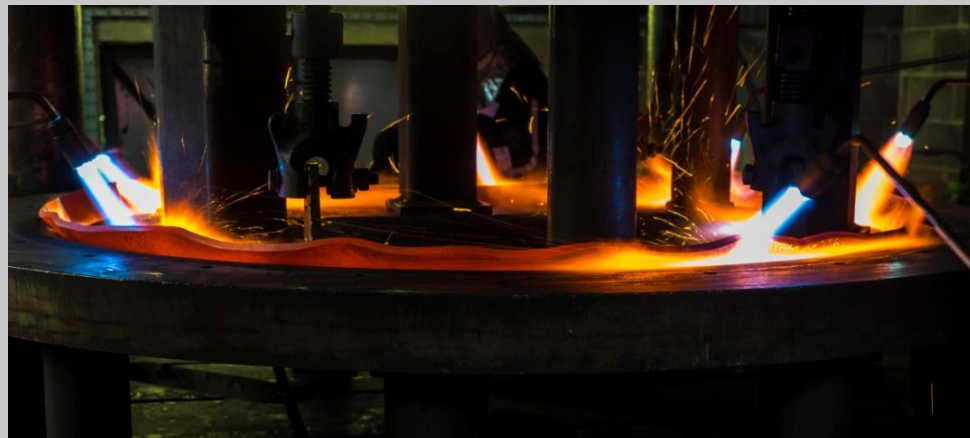


Smokebox door



Smokebox

Smokebox door pressed from CorTen steel



Smokebox



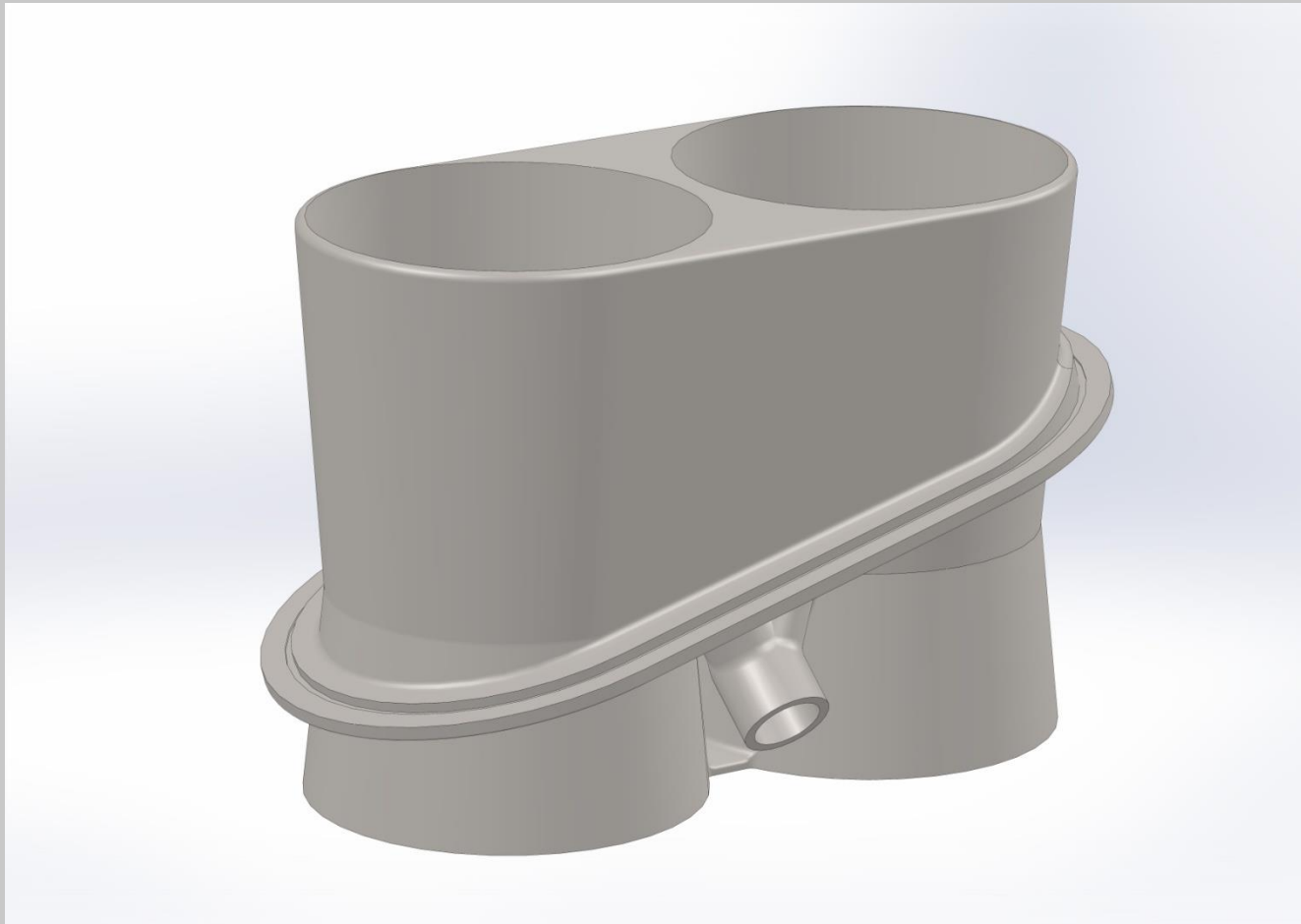
Smokebox door frame to be machined from slab



Smokebox



Chimney pattern and casting ordered



Progress

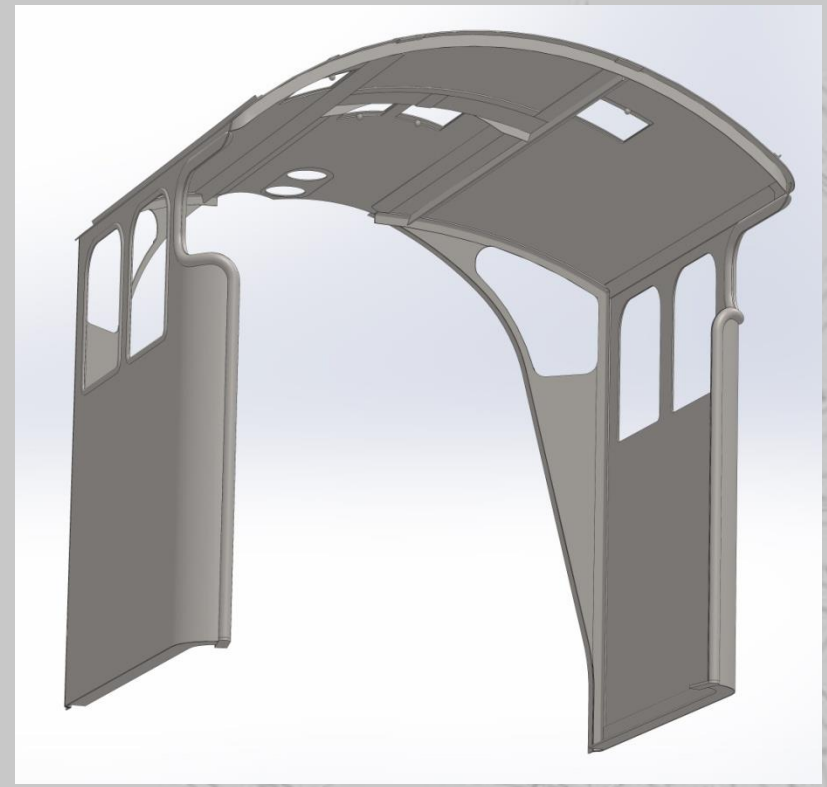
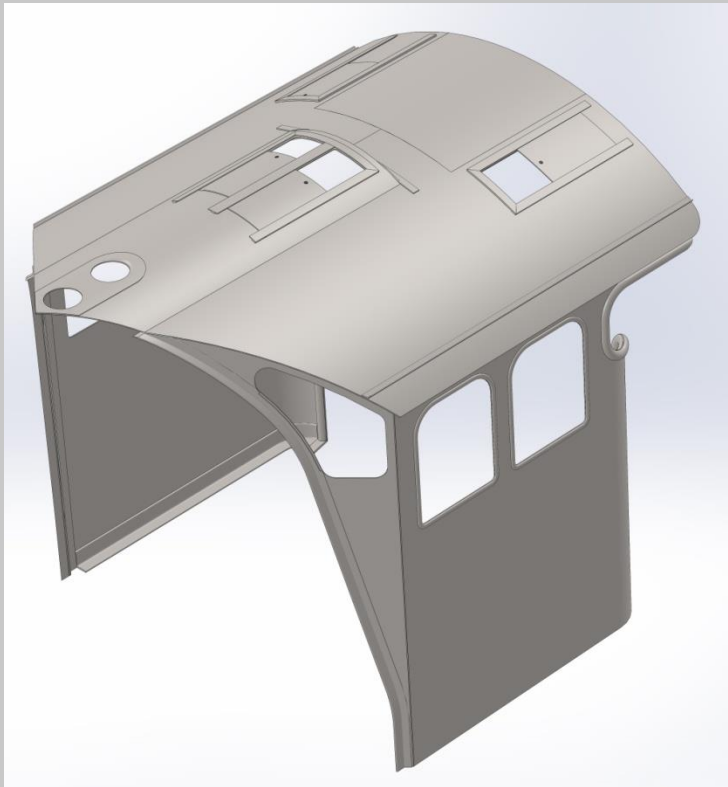
Frames and footplating



Cab

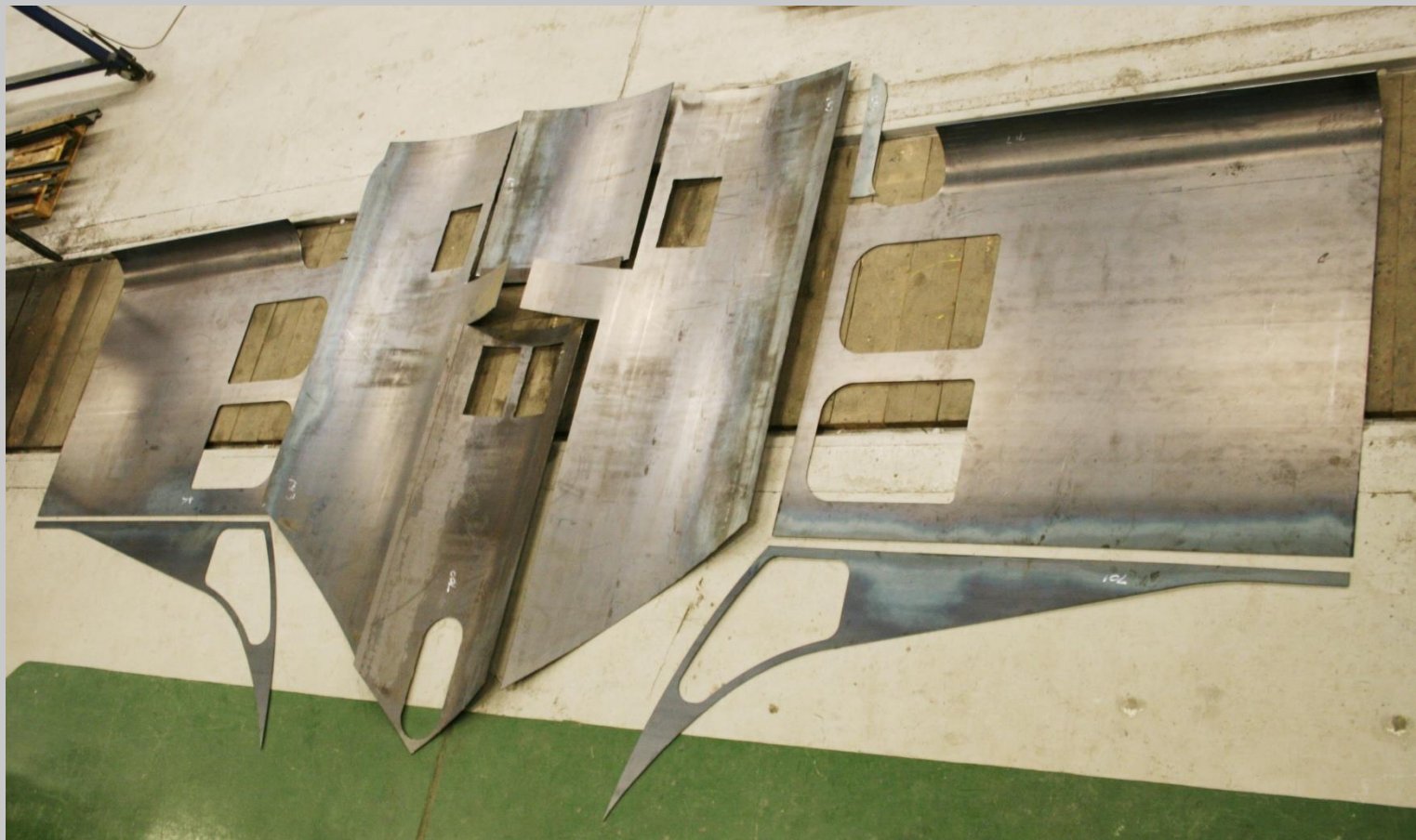


Cab 3D model



Cab

Cab kit



Cab



Cab assembly



Electrical system



The A1 Electrical System – Starting from a Clean Sheet

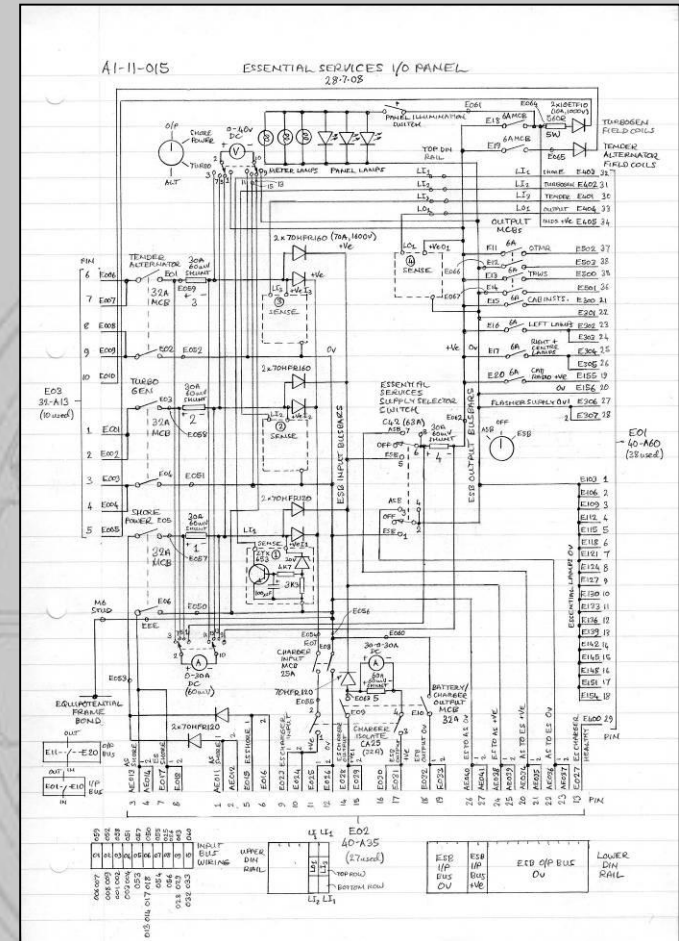
- Some UK steam firsts for the A1:
 - On-board power supply for TPWS and OTMR
 - Two independent electrical generators
 - Full electronic battery charge control
 - Dual redundant power supplies
 - Fixed head, tail and marker lamps to GM/RT 2483, for speeds above 60 mph
 - Lamp health indicators in the cab
 - Low Smoke Zero Halogen (LS0H) wiring and enclosures used throughout
- and even...
 - a 'Hazard Warning' mode to flash the headlamps in an emergency
 - and a mobile phone charger!



Electrical system

Some Statistics

- 31 new schematic diagrams to document the design
- 3 miles (4.9 km) of wire on the loco and tender
- Over 9,000 individual electrical and electronic components, costing £17,000 - less than 0.6% of the total build
- 52 military connectors containing more than 500 separate contacts
- 230 separate electrical wire runs
- 36 MCB-protected circuits for power supplies and connected loads



Essential Services I/O Panel Schematic

Electrical system

Control and Protection

- Two separate Input/Output Panels:
 - ES I/O Panel under driver's seat, with TPWS
 - AS I/O Panel under the fireman's seat, with OTMR
 - Miniature Circuit Breakers (MCBs) to protect each input and output circuit
- If one supply fails, all loads can be switched to the other supply
- Two Control Panels - mounted above the crew seats



Essential Services
I/O Panel



Auxiliary Services I/O
Panel with OTMR above



Essential Services Control Panel

Electrical system



Lighting the Way

- New design of headlamp to meet intensity requirements of GM/RT 2483:
 - designed and built by Optical Physicist, Alan Green
 - daytime headlamp equivalent to a 150W halogen bulb (3 car headlamps)
 - uses 7 high-power LEDs, consumes less than 25W
 - mounted in a custom housing, sponsored and built by John Beesley
- New design of marker and tail lamps, to GM/RT 2483:
 - fit into original Stones housings
 - include red and white LEDs with a beam splitter, selected electronically



John Beesley's custom headlamp housing



LED marker lamp assembly

Electrical system



Pimp my Pacific!

- We also installed LED strip lighting outside the frames - strictly for cleaning and maintenance purposes of course...



...but they do look good too



Electrical system



'The Royal Borderer', Doncaster to Edinburgh and return, 22nd October 2010

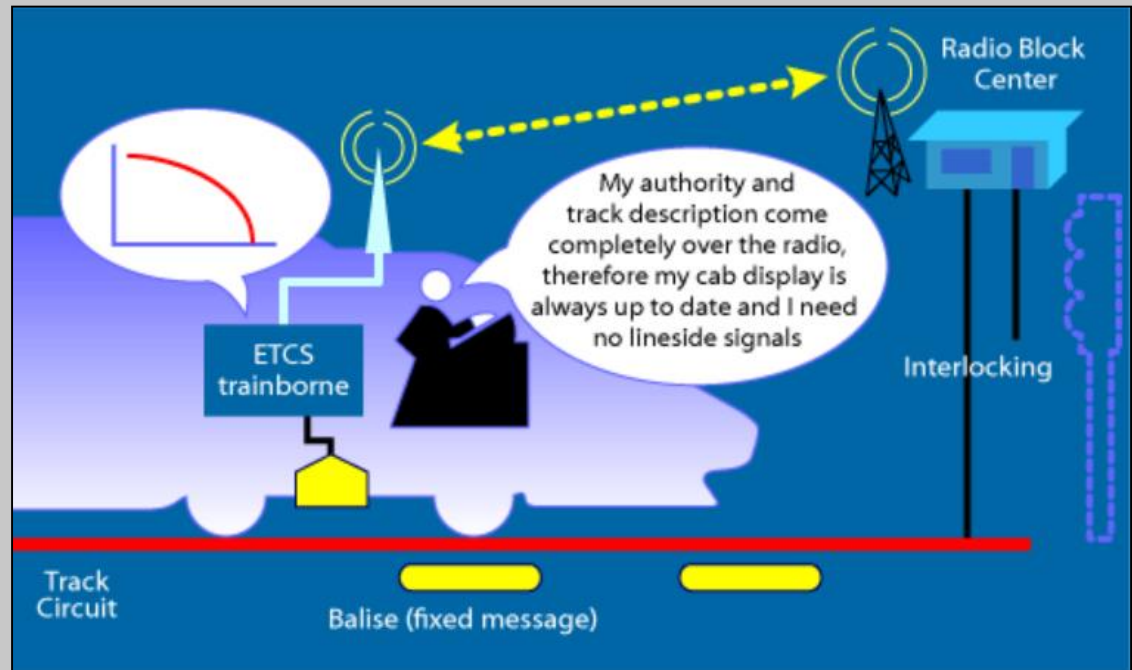


ERTMS for the A1 and P2



ERTMS Level 2

- ERTMS Level 2 is operating on the Cambrian Coast line in Wales
- The system requires a complex new installation on all trains using the line
- There has been much discussion about the practicality of installing ERTMS on steam locomotives



Level 2 ERTMS schematic

Raising the money

£5m sounds a lot of money but...

- Over £4m raised by A1SLT since 1990
 - *Tornado* construction
 - E21249 support coach overhaul and conversion
 - Ongoing maintenance and overhaul
 - £10m if include volunteer time
- Vulcan to the Sky raised over £7m to get Vulcan XH558 back into the air
- Welsh Highland Railway raised over £25m to re-open a 25 mile railway



Raising the money



Finding £5m - fundraising initiatives

- The Founders Club
- Regular donations by Covenant
- Sponsoring a component by Dedicated Donation
- Commercial sponsorship
- The Boiler Club
- Loan finance
- Legacies
- Grants



Raising the money



The Founders Club

- We estimated that the pre-launch phase would require at least £100,000
- We sought at least 100 people each donating £1,000 in up to four payments of £250 by standing order
- These funds are being used to get the project to the point of cutting No. 2007's frames

Membership of The Founders Club has now closed but exceeds 360, worth over £450,000

Raising the money



Covenanting – a P2 for the price of a pint!

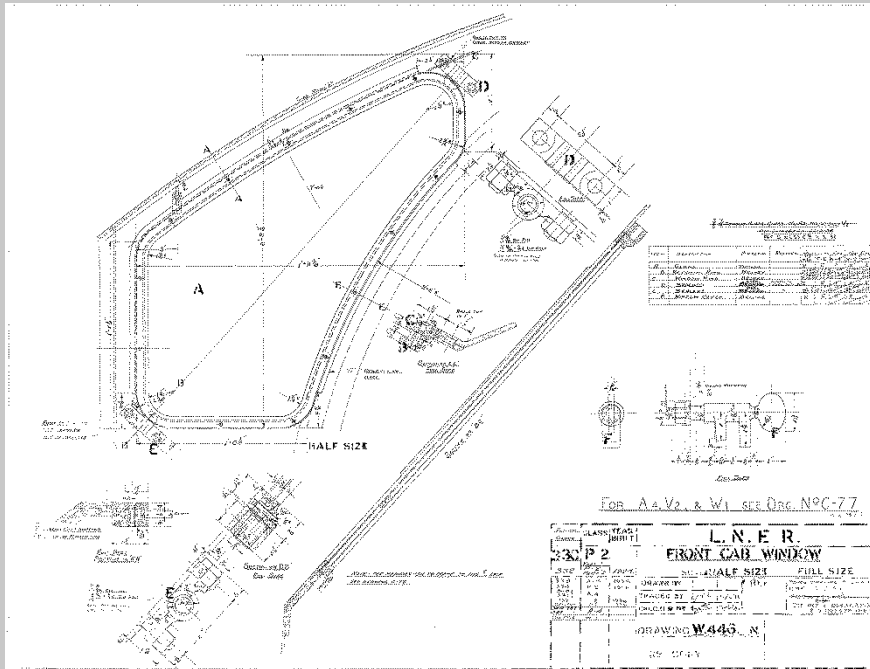


- £10pm by standing order
- Price of a pint in North East now £3.10 (up from £1.25 in 1990)
- GAD makes every £10 worth £12.50
- Target of 2,000 £10 equivalents to raise £2m
- **Over 680 covenantors already signed up worth over £1m**

Raising the money



Sponsoring a component – dedicated donations



Over £120,000 already pledged

- From as little as £25 to in excess of £50,000
- Payable either as a single donation or monthly by standing order
- Regular release of components
- Benefits to include an A4 copy of the drawing, a photograph of the component, inclusion in the Roll of Honour
- GAD also applies making every eligible donation worth 25% more
- Launched in July 2014 with a target of raising £1.1m
- Contact Mark & Mandy Grant on dedicated.donations@p2steam.com

Raising the money



The boiler club

- Boiler and associated systems will cost around £600,000
- We are seeking at least 300 people each donating £2,000 in up to 40 payments of £50pm by standing order
- Special benefits for members of The Boiler Club:
 - Reserved seat on No. 2007's first main line train
 - Reasonable access to No. 2007 at all times
 - Opportunity to join one of the teams building No. 2007 and first choice of other components to sponsor
 - Exclusive Boiler Club badge and limited edition version of the first official painting of No. 2007 Prince of Wales with No. 60163 Tornado
 - Special Boiler Club day with Tornado

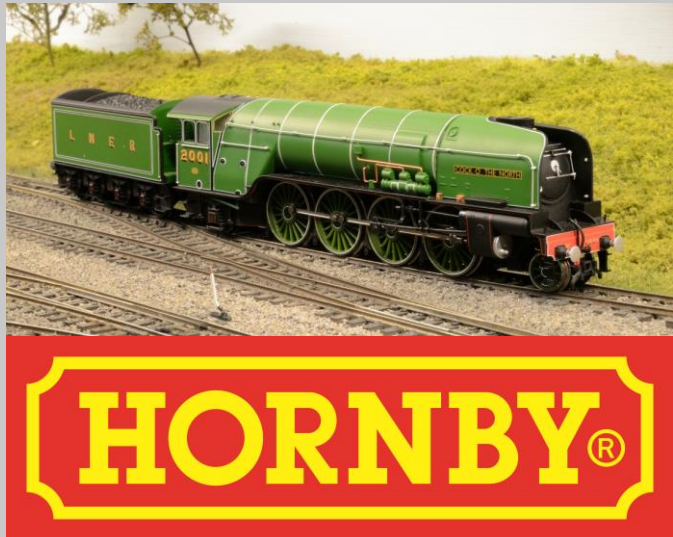
86 members so far, with around £240,000 already pledged

Raising the money



Commercial sponsorship

- As with *Tornado*, we are working to secure the backing of the best of British business
- The high-profile name will unlock many new opportunities
- Fruitful discussions already started with several potential sponsors
- Target of £1.1m in benefits-in-kind over the duration of the project



Questions and answers

