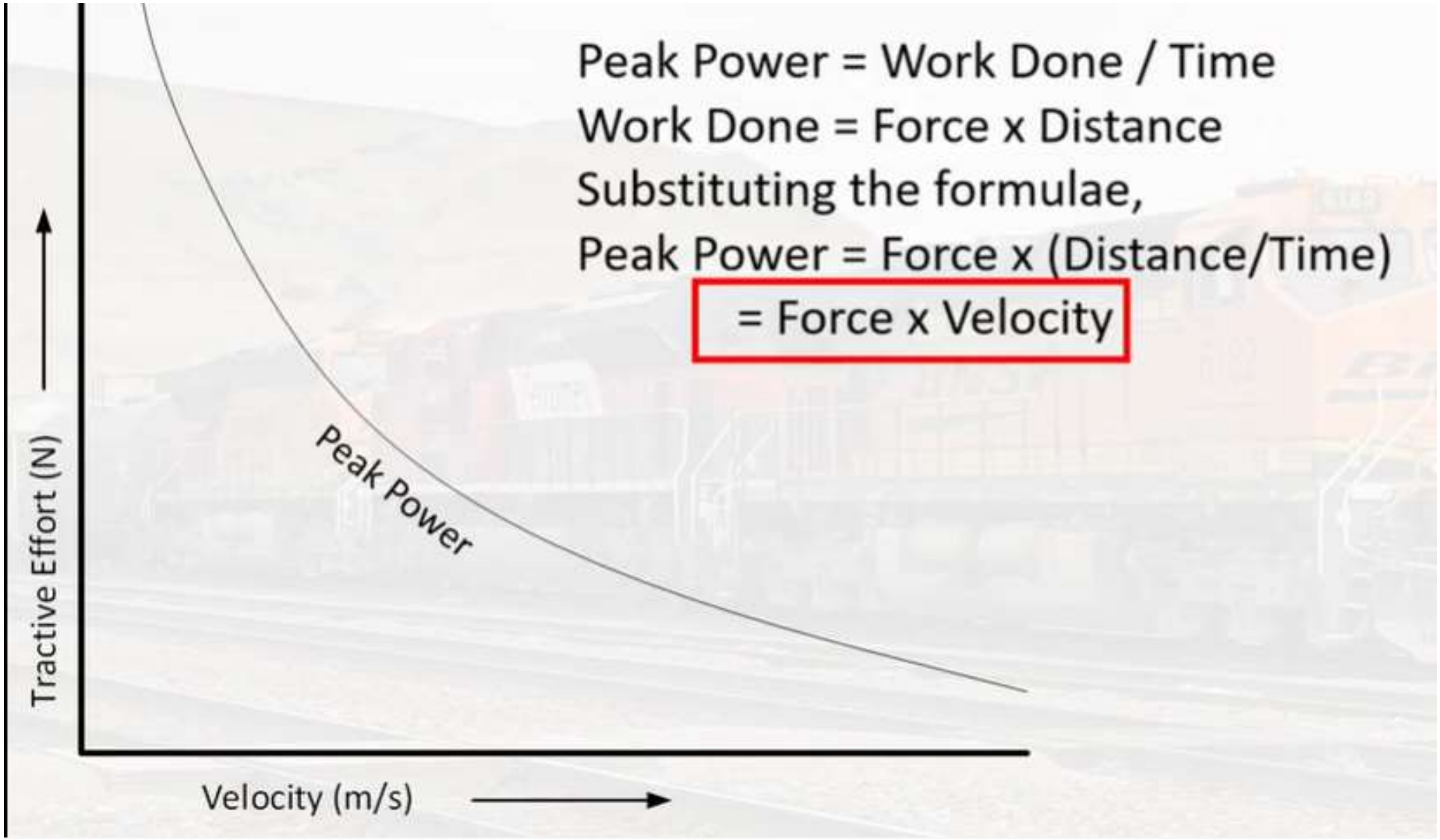
Train Sets

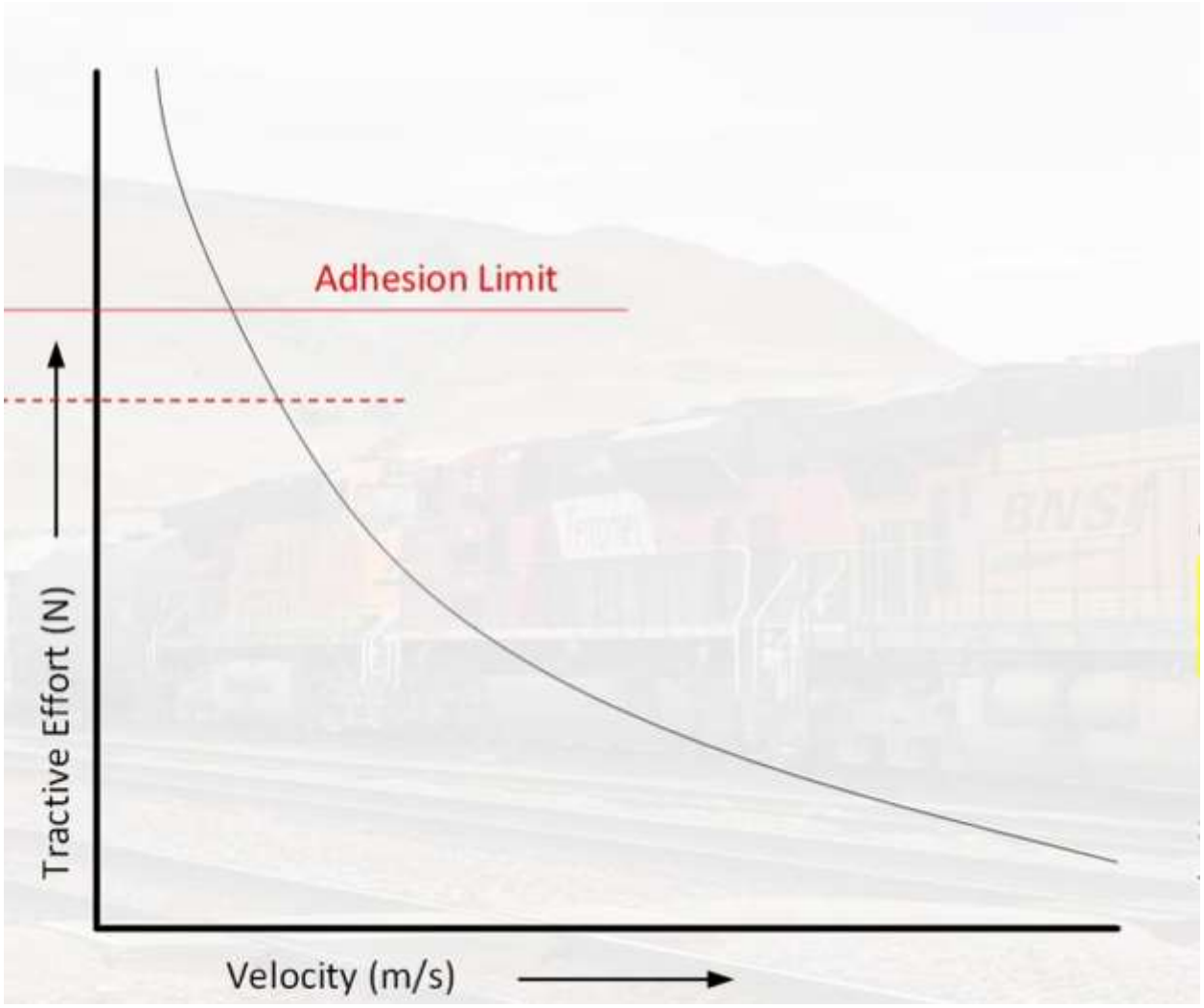
Why and How

Shubhranshu, IRSME ‘83
Chief Administrative Officer
Rail Wheel Plant, Bela

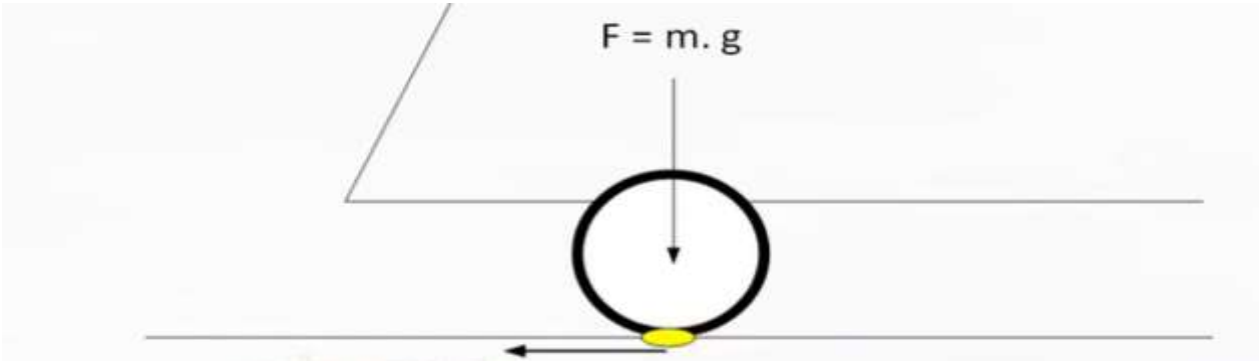
8 Feb, 2021



Peak Power Curve



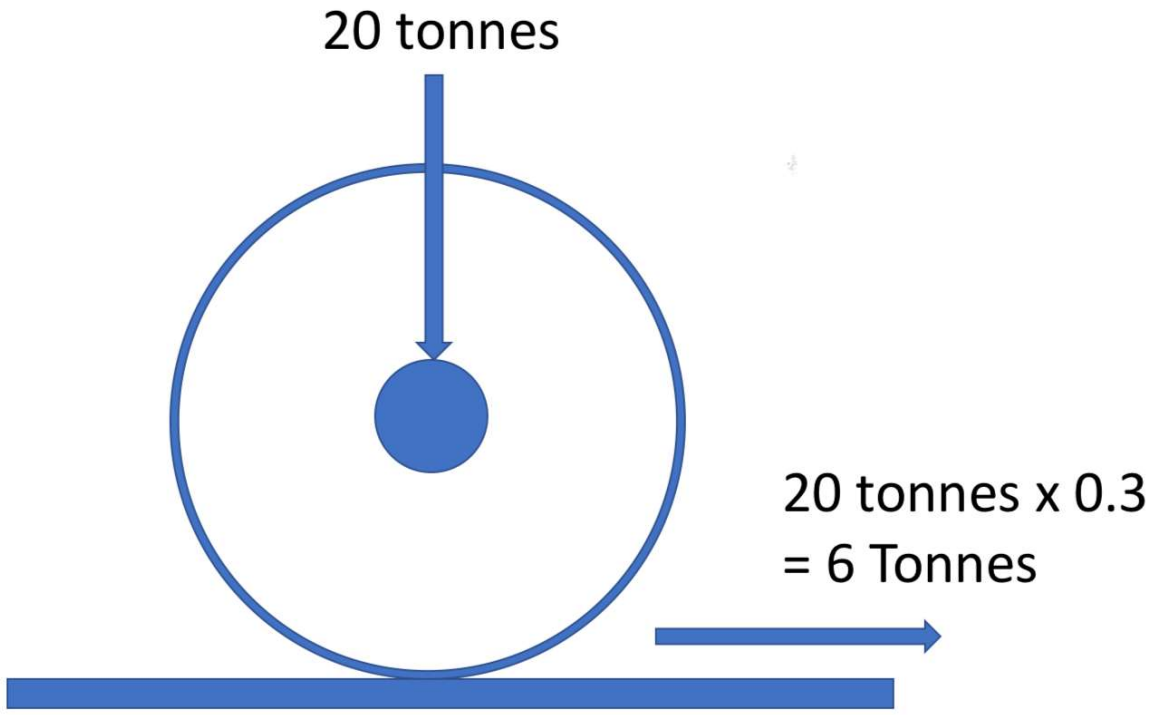
Adhesion Limit



Frictional Force = μ. F = Maximum forward force a wheel can apply on rail before it starts slipping

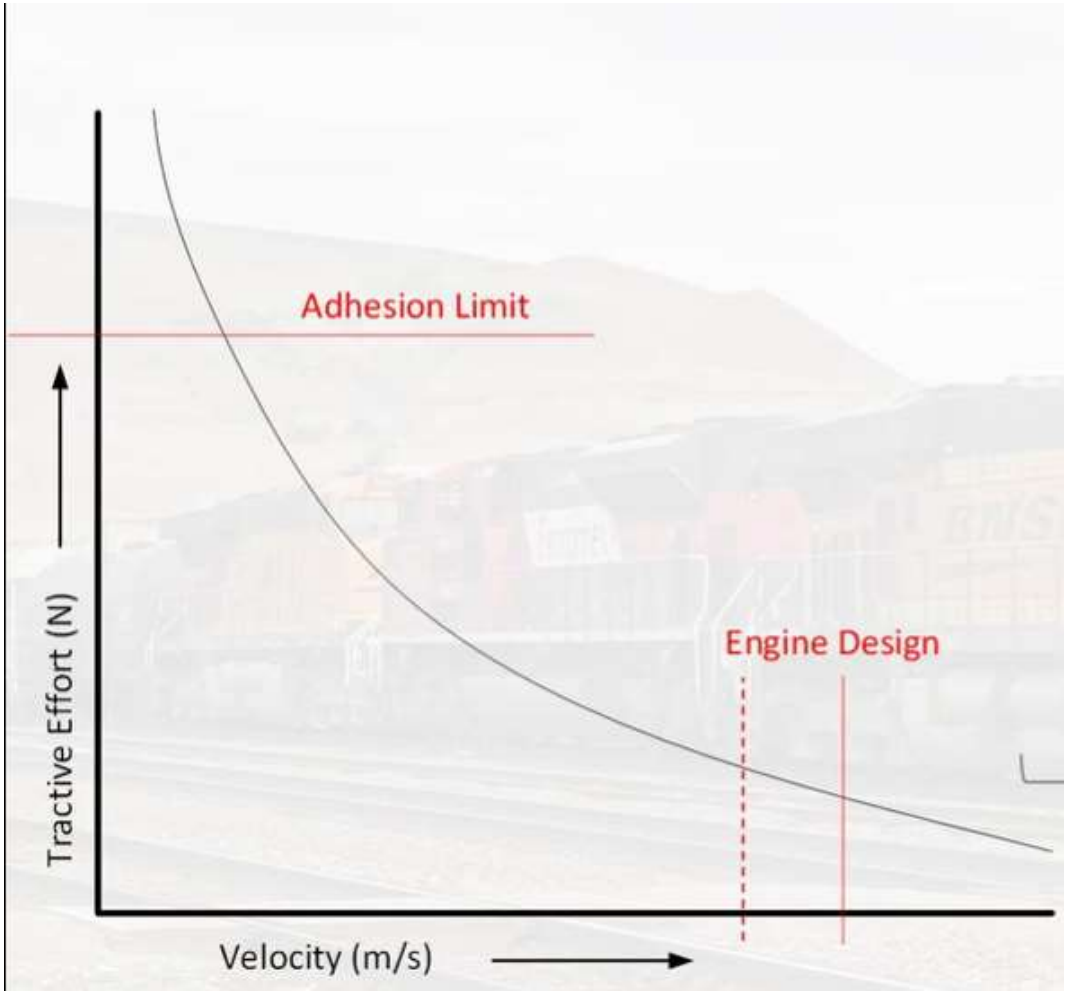
Coefficient of friction: typically on railways it is between 0.35 and 0.5, whilst under extreme conditions it can fall to as low as 0.05. Thus a 100-tonne locomotive could have a tractive effort of 350 kilonewtons, under the ideal conditions (assuming sufficient force can be produced by the engine), falling to a 50 kilonewtons under the worst conditions

Why is there an Adhesion Limit?

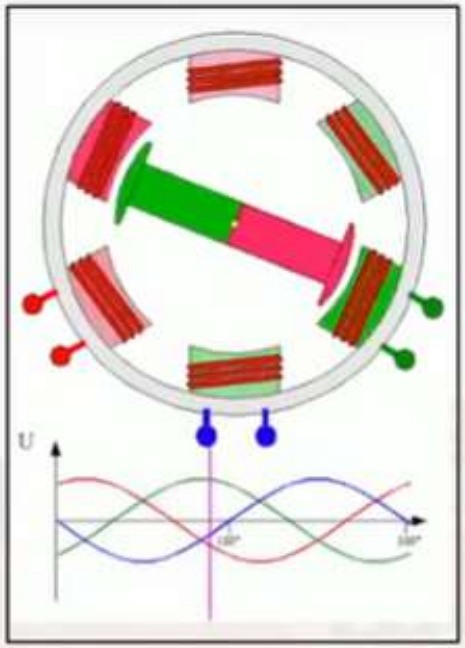


A six axle 20 t loco will give
max 36 tonnes tractive effort

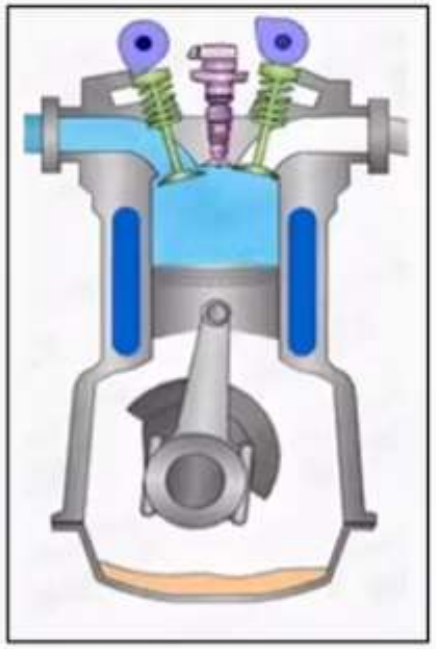
The Law of Rail Traction


Adhesion Limit
Engine Design
Tractive Effort (N)
Velocity (m/s)

Speed Limit



- Motor heating limitation
- High centrifugal force at high RPM
- Insulation breakdown



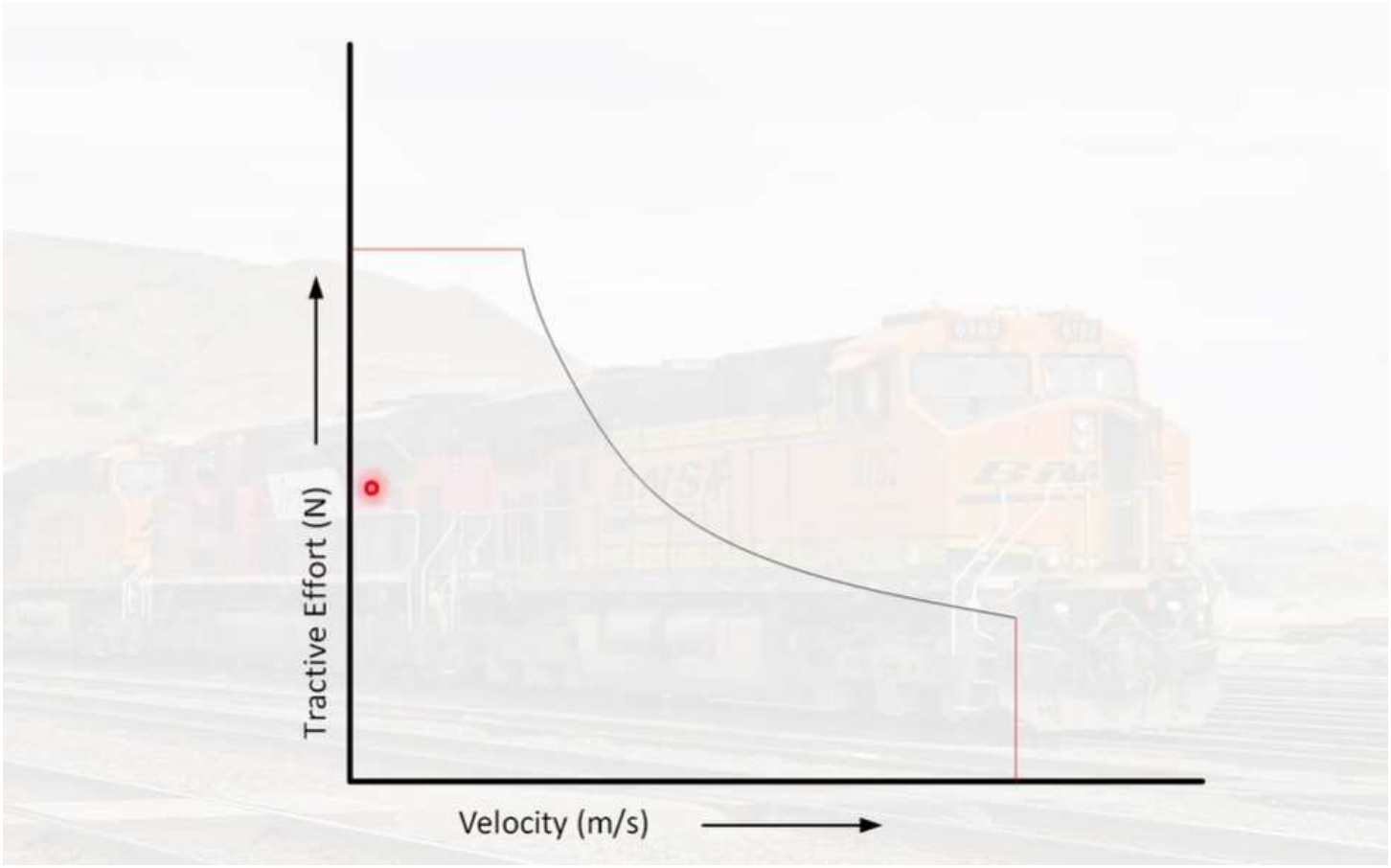
- Valve open/close times
- Fuel Burn time
- Fatigue Limits

Why is there a Speed Limit?

Other Factors Limiting Maximum Speed

- **Bearing Design**
- **Vibrations**
- **Mechanical Transmission System**
- **External - Tracks and Structures**

Why is there a Speed Limit?



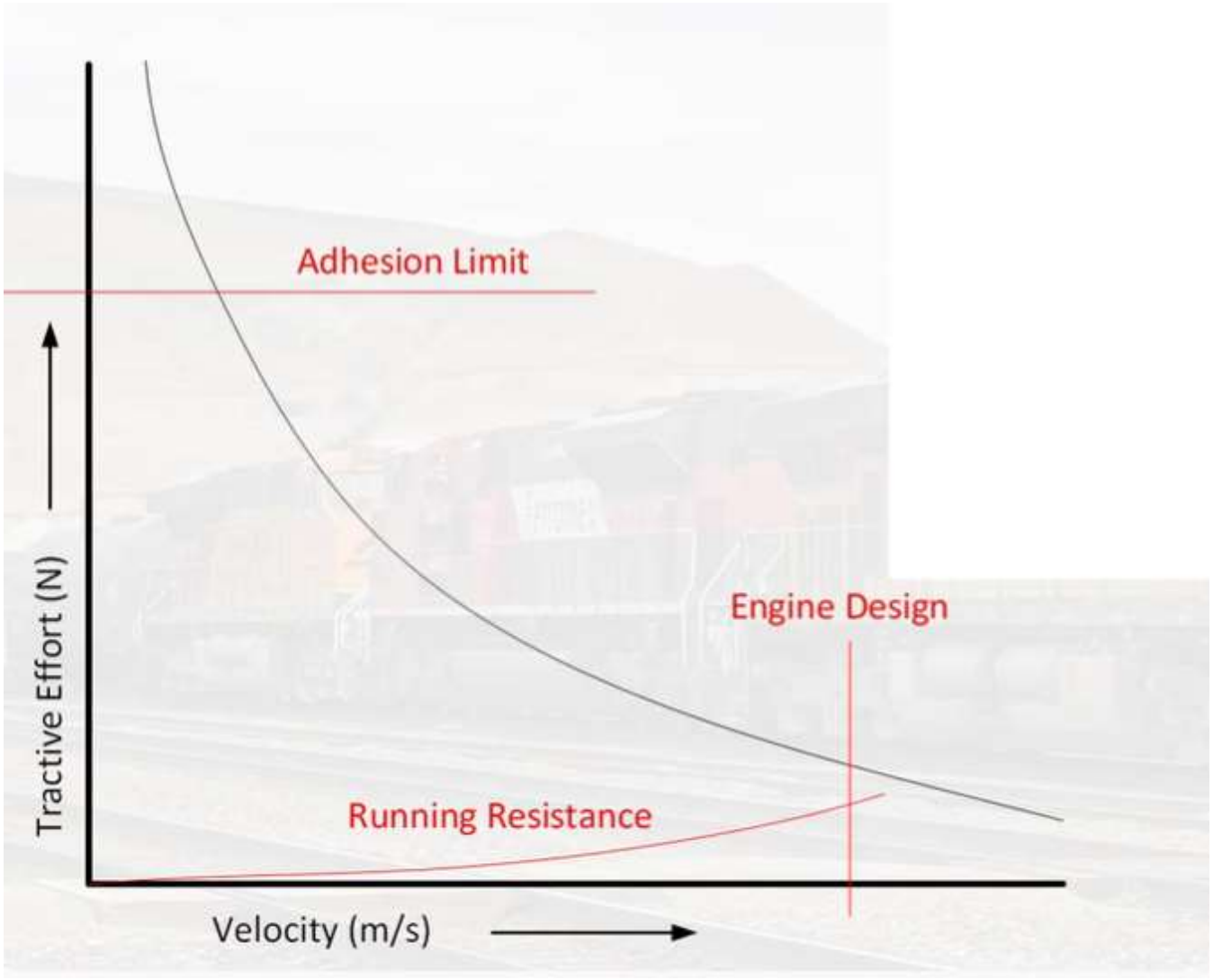
Tractive Effort of a Locomotive

Davis Equation: $R = A + Bv + CDv^2$

https://www.coalstonewcastle.com.au/physics/resistance/

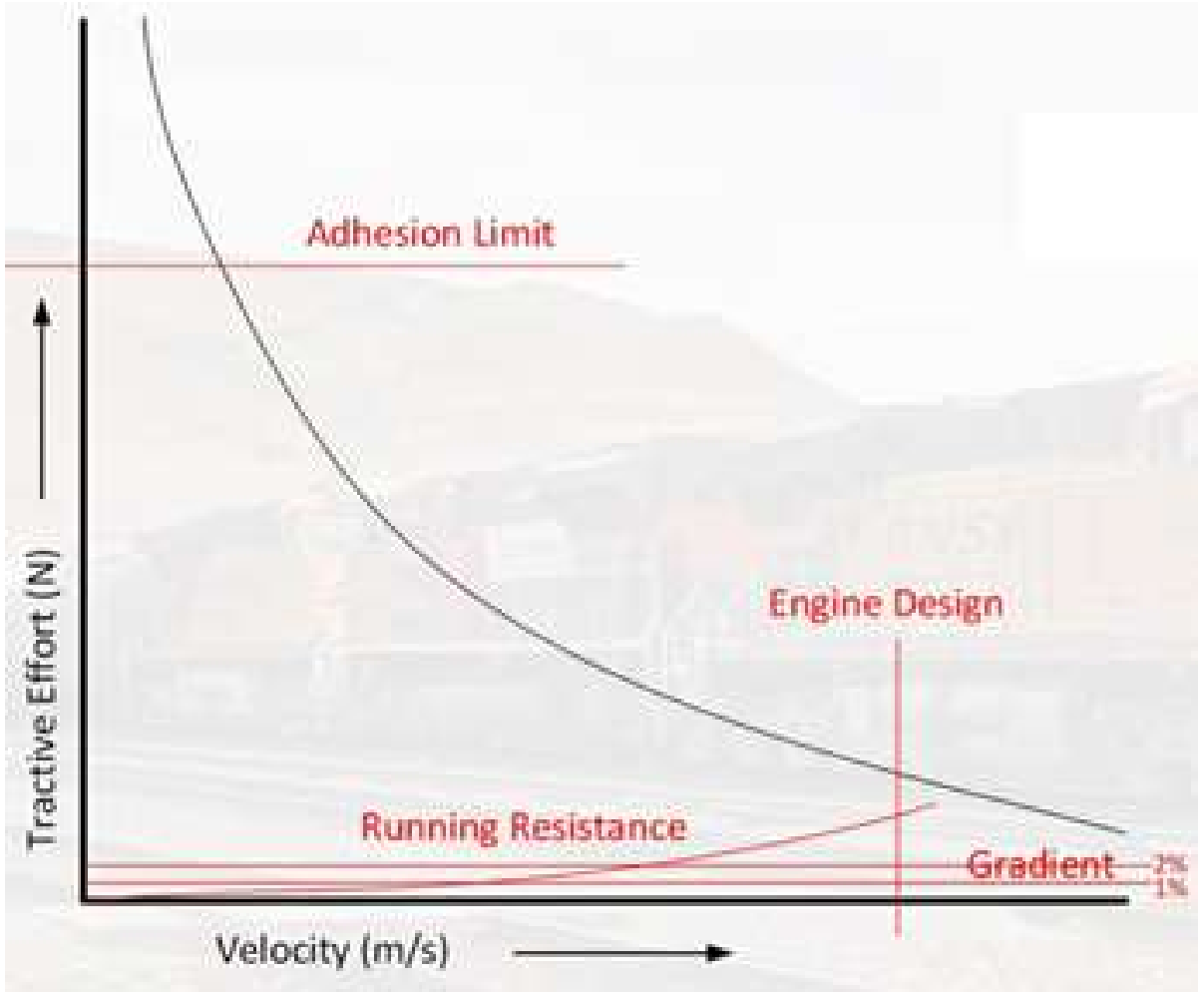
A	B	C & D
Journal / Roller Bearing Resistance	Flange friction	Head-end wind pressure
Rolling resistance	Flange impact	Skin friction on the side of the train
Track resistance	Rolling resistance wheel/rail	Rear drag
	Wave action of the rail	Turbulence between cars
		Yaw angle of wind tunnels

Resistance to Movement of a Loco

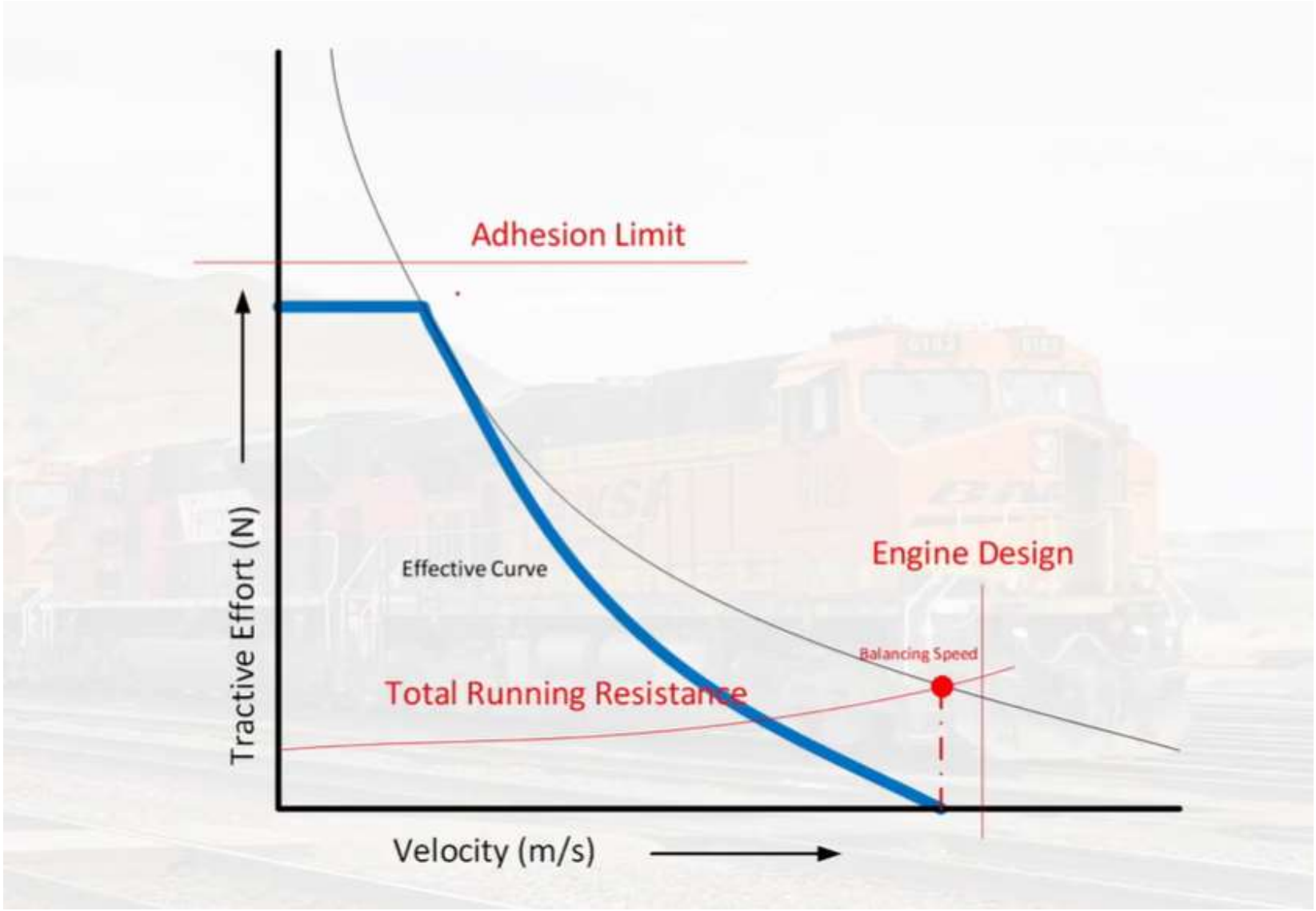


How the Resistance Behaves

Vehicle Design to Minimise Air Drag



Add up All Resistances



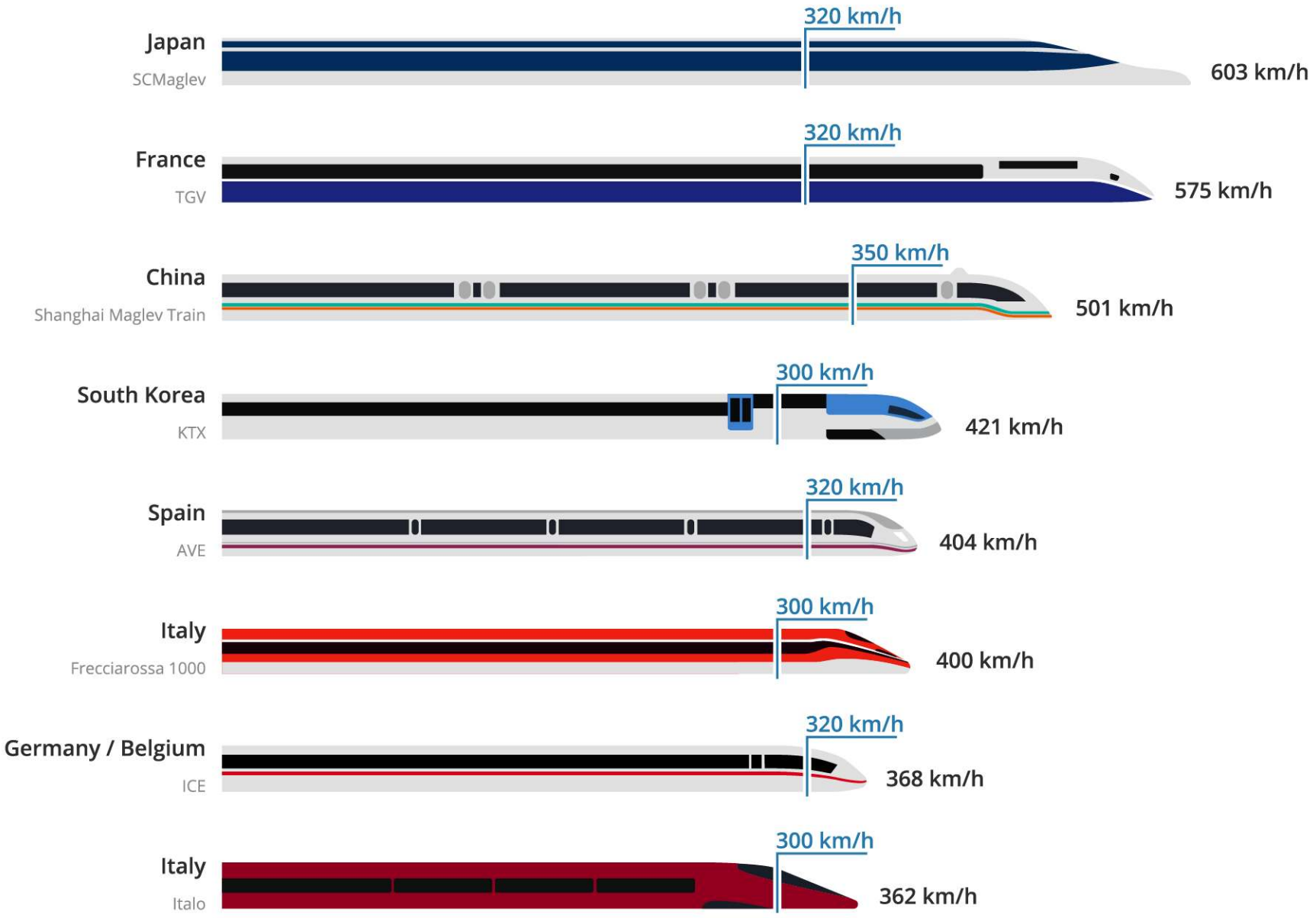
Actual Tractive Effort Available for Haulage

TRAINSETS – THE GENRE

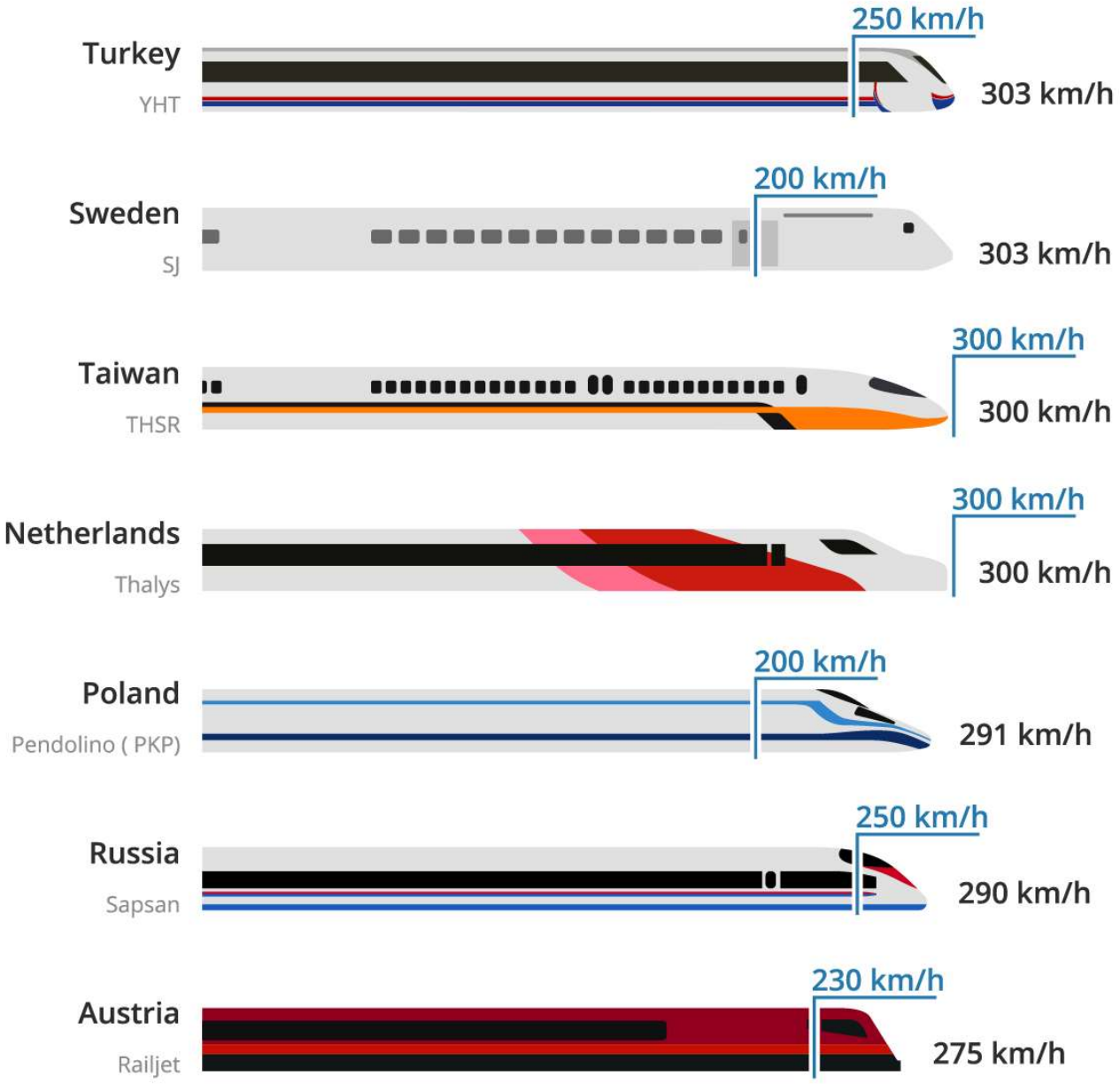
JAPAN – THE LEADER

- Japan's Tokaido Shinkansen opened in 1964 to increase passenger capacity in the Tokyo–Osaka corridor.
- Pessimists had predicted a slump in rail travel with passengers flocking to planes and motor vehicles instead
- But, the 200kmph max speed dramatically boosted the rail travel and brought commuters back to rail.
- The so-called ‘bullet train’ revolutionized the idea of high-speed rail travel

The world


Japan
SCMaglev
320 km/h
603 km/h
France
TGV
320 km/h
575 km/h
China
Shanghai Maglev Train
350 km/h
501 km/h
South Korea
KTX
300 km/h
421 km/h
Spain
AVE
320 km/h
404 km/h
Italy
Frecciarossa 1000
300 km/h
400 km/h
Germany / Belgium
ICE
320 km/h
368 km/h
Italy
Italo
300 km/h
362 km/h

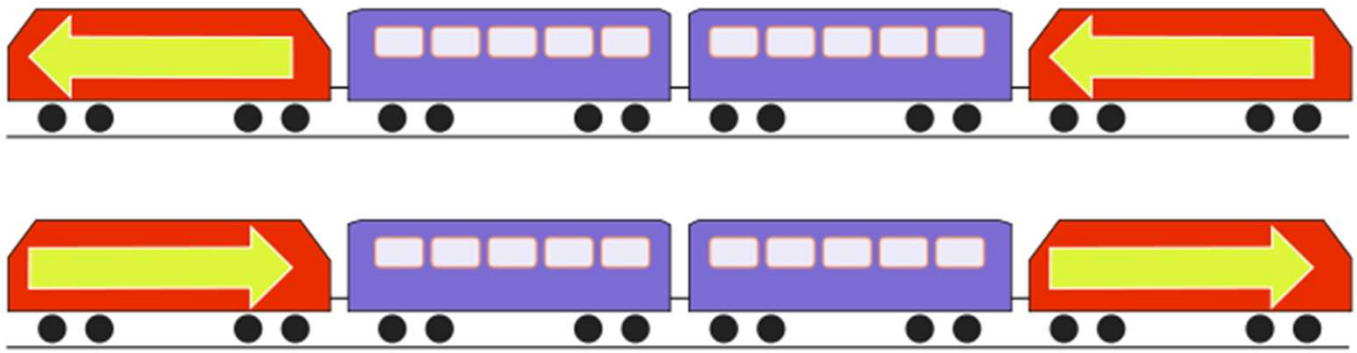
The world


Turkey
YHT
250 km/h
303 km/h
Sweden
SJ
200 km/h
303 km/h
Taiwan
THSR
300 km/h
300 km/h
Netherlands
Thalys
300 km/h
300 km/h
Poland
Pendolino (PKP)
200 km/h
291 km/h
Russia
Sapsan
250 km/h
290 km/h
Austria
Railjet
230 km/h
275 km/h

TRAINSETs
Technical & Operational Benefits

- The entire train is built by one company, as a single supply.
- Loco and carriage builders were never on the same page.
- Technology ownership created innovations:
  - Speed, comfort, noise and vibration free ride, air-conditioning
  - Warranty and service support
- Identical maintenance schedules

Loco hauled trains



- Constraint is the loco axle load 22+ tonnes
  - Maximum speed, bridges, concentrated tractive effort
- Maximum power exploited per axle – 600-1000 hp
- First trainsets were no different from push-pull configurations.

Speed– IR Scenario

Train Name	Route	Distance (KM)	Time (Minutes)	Max Speed (Kmph)	Avg Speed (Kmph)	Coaches
Gatimaan Express	NDLS-GWL	305	186	160	112	8
Bhopal Shatabdi	NDLS-BPL	707	510	150	100	18
Mumbai Rajadhani	NDLS-MMCT	1,384	942	140	88	20
Howrah Rajadhani	NDLS- HWH	1447	1015	130	85	21
Chennai Rajadhani	NDLS-MAS	2175	1695	130	77	18
Godavari	HYB-VSKP	709	755	110	57	24

MEMUs/DEMUs vs. Loco Hauled Passenger Trains

Loco Hauled Passenger Services

Train No.	Route	Distance (KM)	Time (Minutes)	Max Speed (Kmph)	Avg Speed (Kmph)	STOPS
55893	RNY-RPAN	123	185	105	39	15
77416	GTL-UBL	50	85	105	35	9

PASSENGER SERVICES WITH MEMU/DEMU

Train No.	Route	Distance (KM)	Time (Minutes)	Max Speed (Kmph)	Avg Speed (Kmph)	STOPS
66032	NLR-SPE	93	120	105	46	12
63507	BWN-ASN	104	113	105	55	14
61634	BINA-BPL	138	135	105	62	6
74620 (DEMU)	BRML-BAHL	135	140	105	58	9

Average Speed Increase by 20 to 35% for the same sectional speed

EBD comparison Loco hauled Vs Train18

	60 kmph	80 kmph	100 kmph	120 kmph	160 kmph
WAP 5 +18 LHB	221m	377 m	571 m	802 m	1369 m
Train 18	147 m	250 m	392 m	555 m	981 m

Why Mainline Trainsets?

Loco hauled Train	Train set
Locomotive hauled	No locomotive, distributed power
Reversal requirements at terminals	No reversal requirement at terminals
Sluggish acceleration & deceleration – 0.2-0.3 m/s^2 Time to 130 kmph – 250- 300 sec. approx	Quick acceleration & deceleration– 0.8-1.0 m/s^2 Time to 130 kmph – 50 sec.
Inferior utilization of on-board space	Maximum utilisation of on-board space
Concentrated wt. in locos; higher coupler forces	Uniform wt. distribution. lower coupler forces
Low redundancy	High redundancy
Lower energy efficient	Higher energy efficiency
Lower maintainability	Higher maintainability

TRAINSETS – Indian Edition

- Broad Gauge – Technology limitations
- Fixed Infrastructure limitations
  - Tracks, Bridges
  - Signal
  - Mixed Traffic – speed differentials
- **Semi High Speed – 200kmph**
- Costs – Indian fares non remunerative
- Maintenance Infrastructure
- Value for Money

Major technical features

- ✓ 160 km/h speed . Test speed- 180 km/h
- ✓ Maximum Design Axle Load – 17 T (Actual–16.5 T)
- ✓ Starting Acceleration – 0.8 m/sec^2
- ✓ Deceleration – 1 m/sec^2
- ✓ 50 % Powering
- ✓ 4 Car Basic Unit. One Pantograph per each BU
- ✓ Wheel Mounted Brake Disc
- ✓ Bogie Control for Brake System as well as Traction

Trainsets – An Upgrade?

Currently

- ✓ Sub-Urban Traffic on EMU trainsets with Distributed Power System
- ✓ MEMU/DEMU Commuter Trains
- ✓ Metro Trains

New addition …

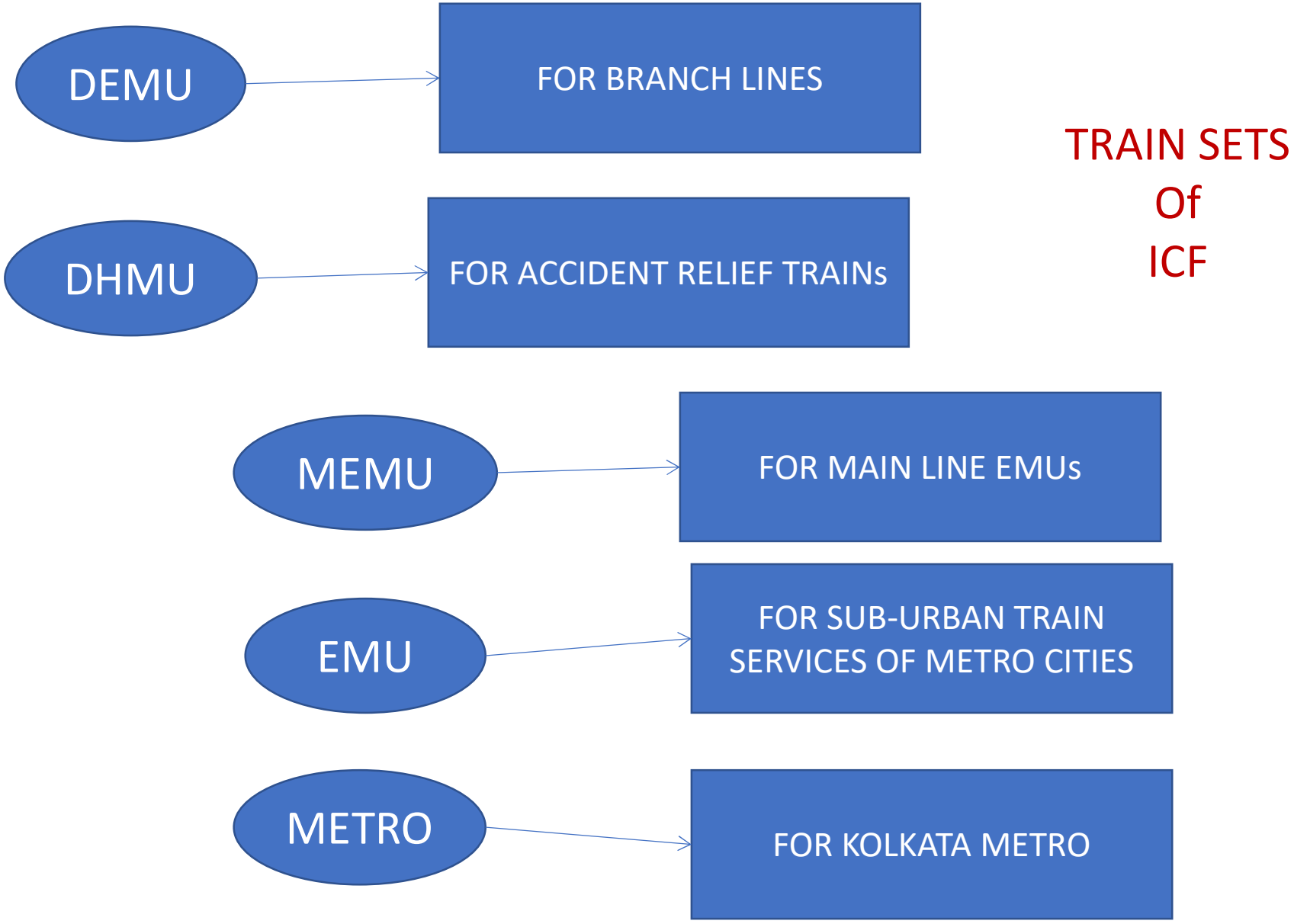
- ✓ Mainline Trainsets

TRAINSETS

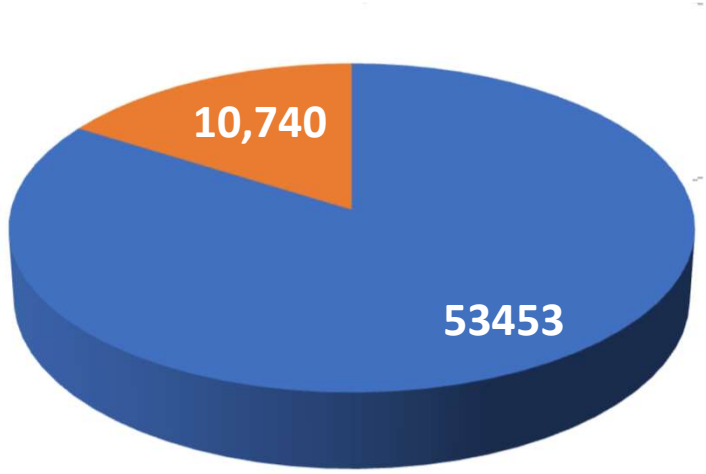
- Synonymous with High Speed
- Distributed Power
  - More than one vehicles powered in a train.
  - Typical High Speed – all axles motored
  - EMU: 1+2, MEMU: 1+3, DEMU: 1+4/5, SPART: 2+1
- Better acceleration: typically 0.7 – 0.8m/sec^2
- Dynamic/Regenerative Braking works on all axles.
- Train 18: 1+1 (50% Powering)

TRAINSETS – No Compromises

- Onboard network – TCMS
- Synchronises traction and braking
- Controls automatic doors
- Air-conditioning controls
- PA/PIS (Passenger Announcement / Pass Info System)
- Entertainment
- Auto detection of Basic Units


DEMU
FOR BRANCH LINES
DHMU
FOR ACCIDENT RELIEF TRAINs
MEMU
FOR MAIN LINE EMUs
EMU
FOR SUB-URBAN TRAIN SERVICES OF METRO CITIES
METRO
FOR KOLKATA METRO
TRAIN SETS
Of
ICF

IR PASSENGER ROLLING STOCK PROFILE



Train 18 – The Vande Bharat Express

Train - 18

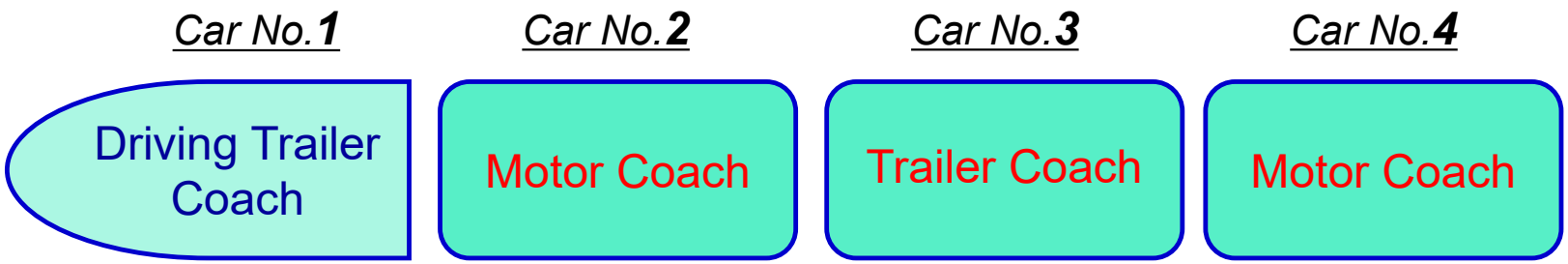
- 16 car train – Shatabdi-like.
- All equipment underslung
- Stainless Steel carbody – Largely based on LHB
- Superior Interiors – seats, wall panels, air-conditioning, lighting
- Automatic Doors
- Bogies – A new genre
  - Fully suspended traction motors
  - Speed potential of 200kmph
  - Air-suspension
  - Calliper brakes

Train - 18

- Four Basic units of four coach each
- Equipment distributed across all four

1. Driving Trailer Coach x 1 – Driver's Cab, Compressor, Batteries
2. Motor Coach 1 – Traction Motors, Convertors
3. Trailer Coach – Transformer, Pantograph, Auxiliary Convertor
4. Motor Coach 2 – Traction Motors, Convertor

The basic unit



Driver's Cab, Compressor, Batteries

Traction Motors, Convertors

Transformer, Pantograph, Auxiliary Convertor

Traction Motors, Convertors

Train - 18

- Maximum speed: 160 kmph
- Axle Load 17 tonnes (The holy grail)
- To be tested at 180 kmph
- Acceleration:

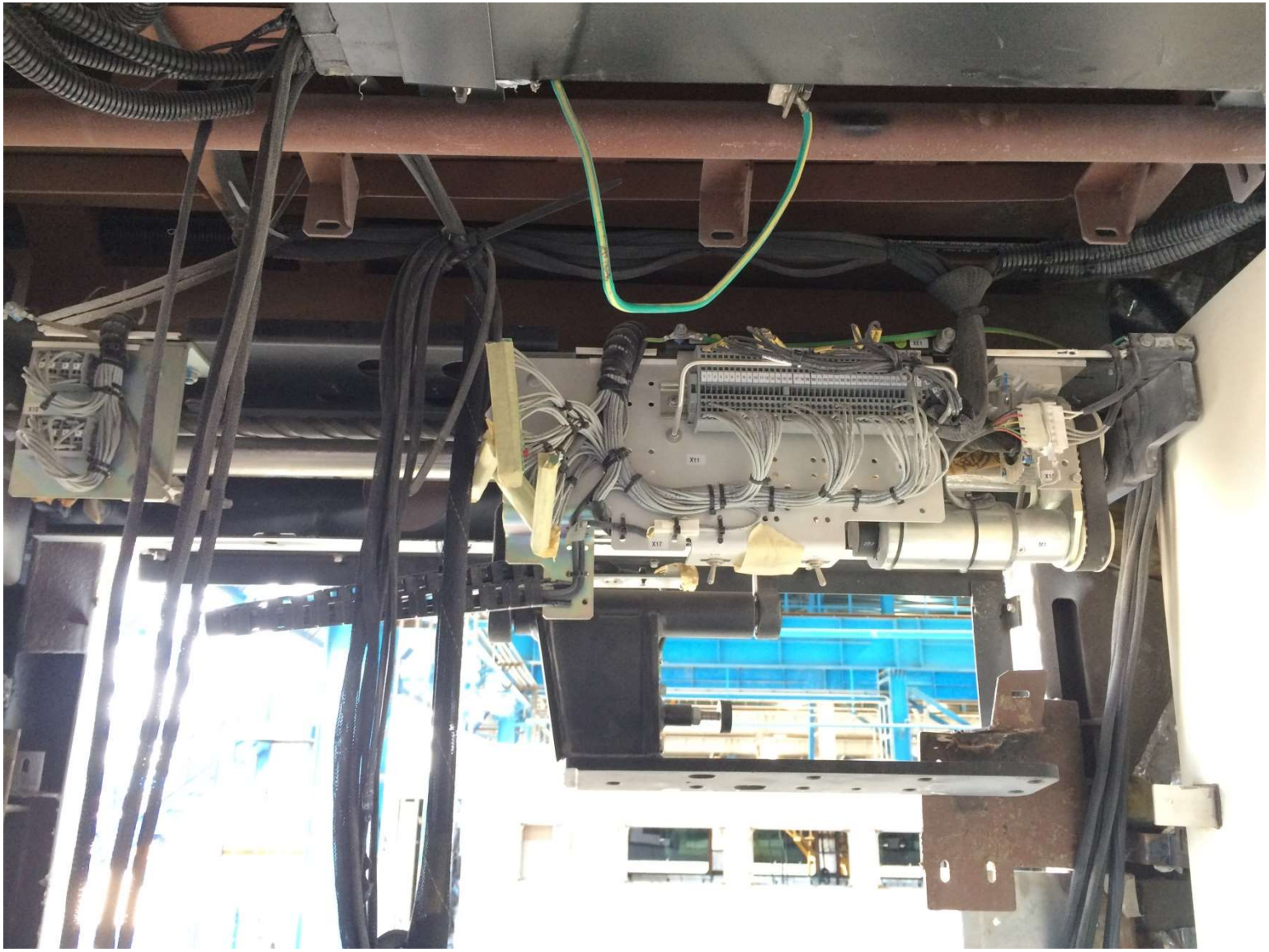
	Train-18	Rajdhani
• 0-40kmph:	0.70m/Sec^2	0.183
• 40-80kmph:	0.62m/Sec^2	0.146
• 80-120kmph:	0.28m/Sec^2	0.060
• 120-180kmph:	0.09m/Sec^2	0.008

Train – 18 Features
The Car Body


DA SHED

The Driving Trailer Coach

Automatic doors



Comfort features

- Better Air-conditioning Diffusers
- Direct and diffused lighting
- Plush seating – CC and Executive, both
- Noise mitigation – sandwich wood-cork floor boards, rubber flooring
- Superior thermal insulation
- Large windows – easy-pull blinds
- Vacuum toilets
- Automatic doors – outside and inside
- Full width gangways

Continuous windows

large from inside

large from inside

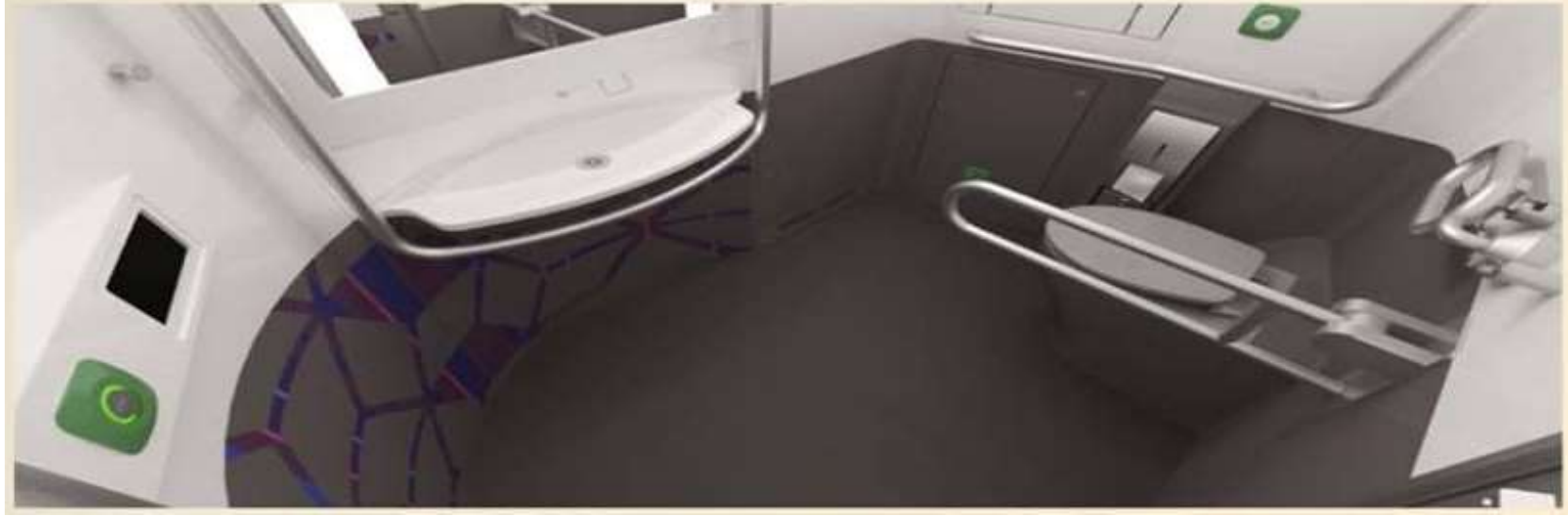
EXECUTIVE CLASS – 56 SEATS

CC – 78 SEATS

CHAIRS

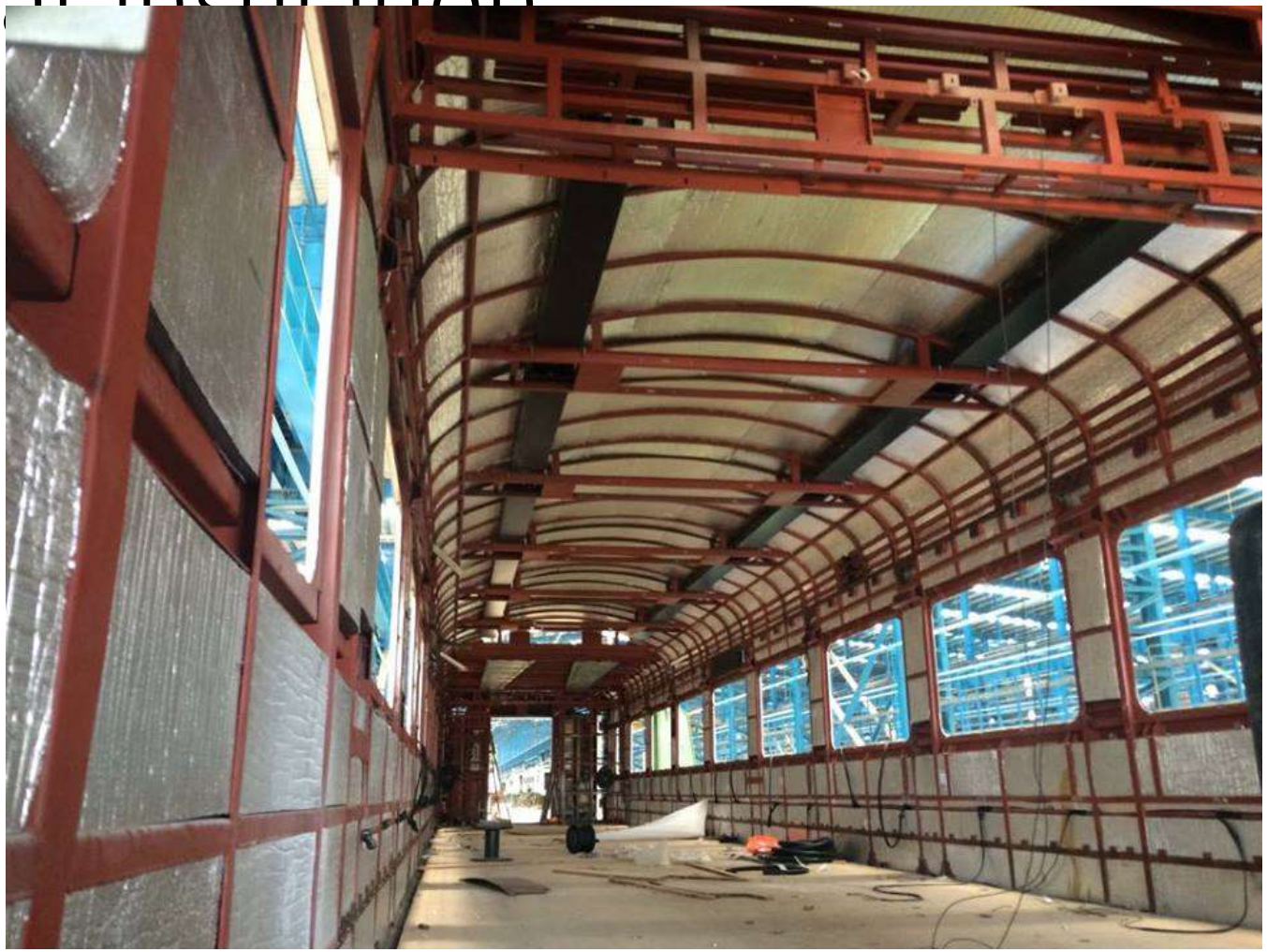
SPACE FOR THE DISABLED

SPACE FOR THE DISABLED



“continuous window”

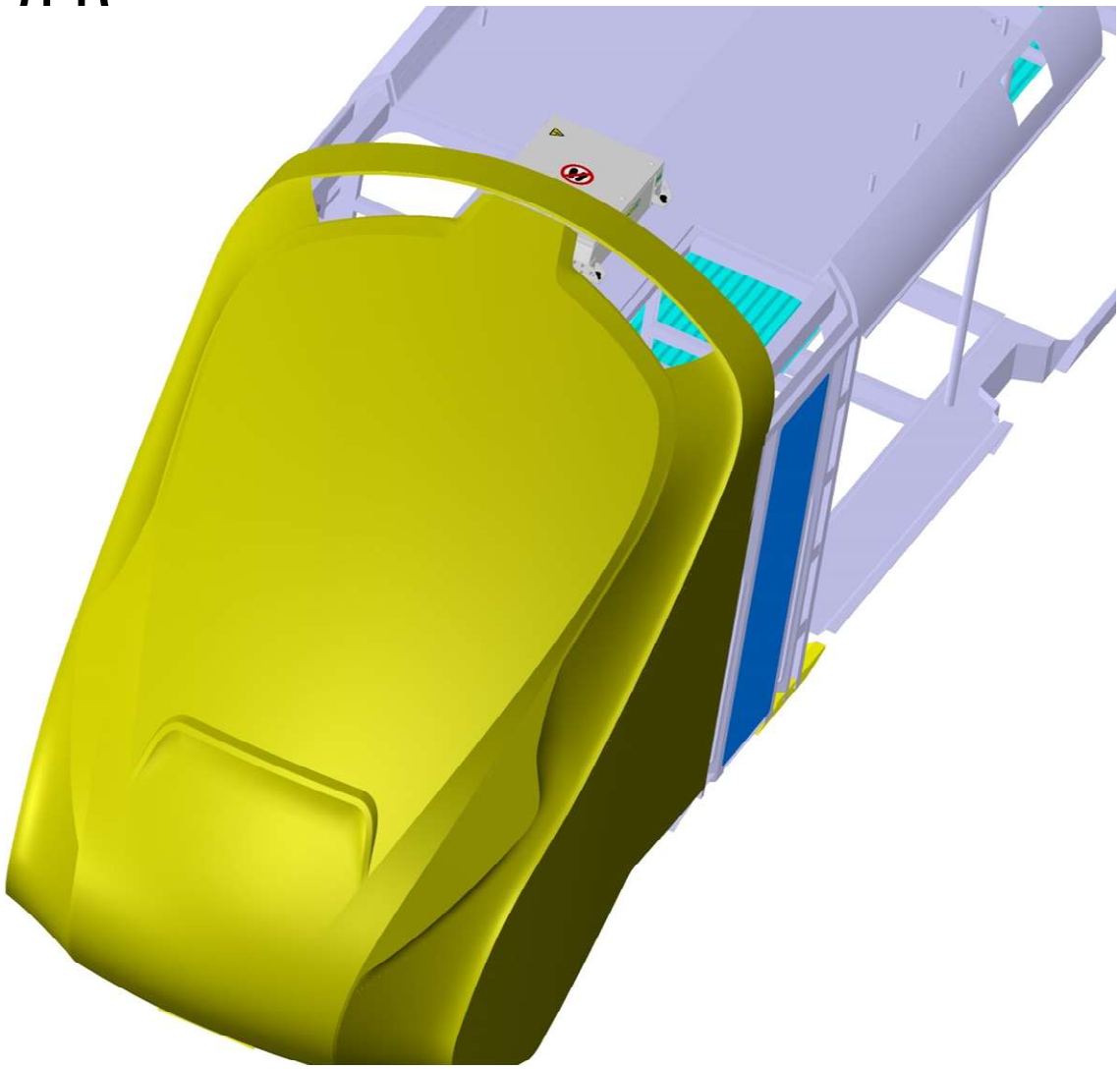
Heat insulation



Special thermal insulation foam

The Driving Trailer Coach

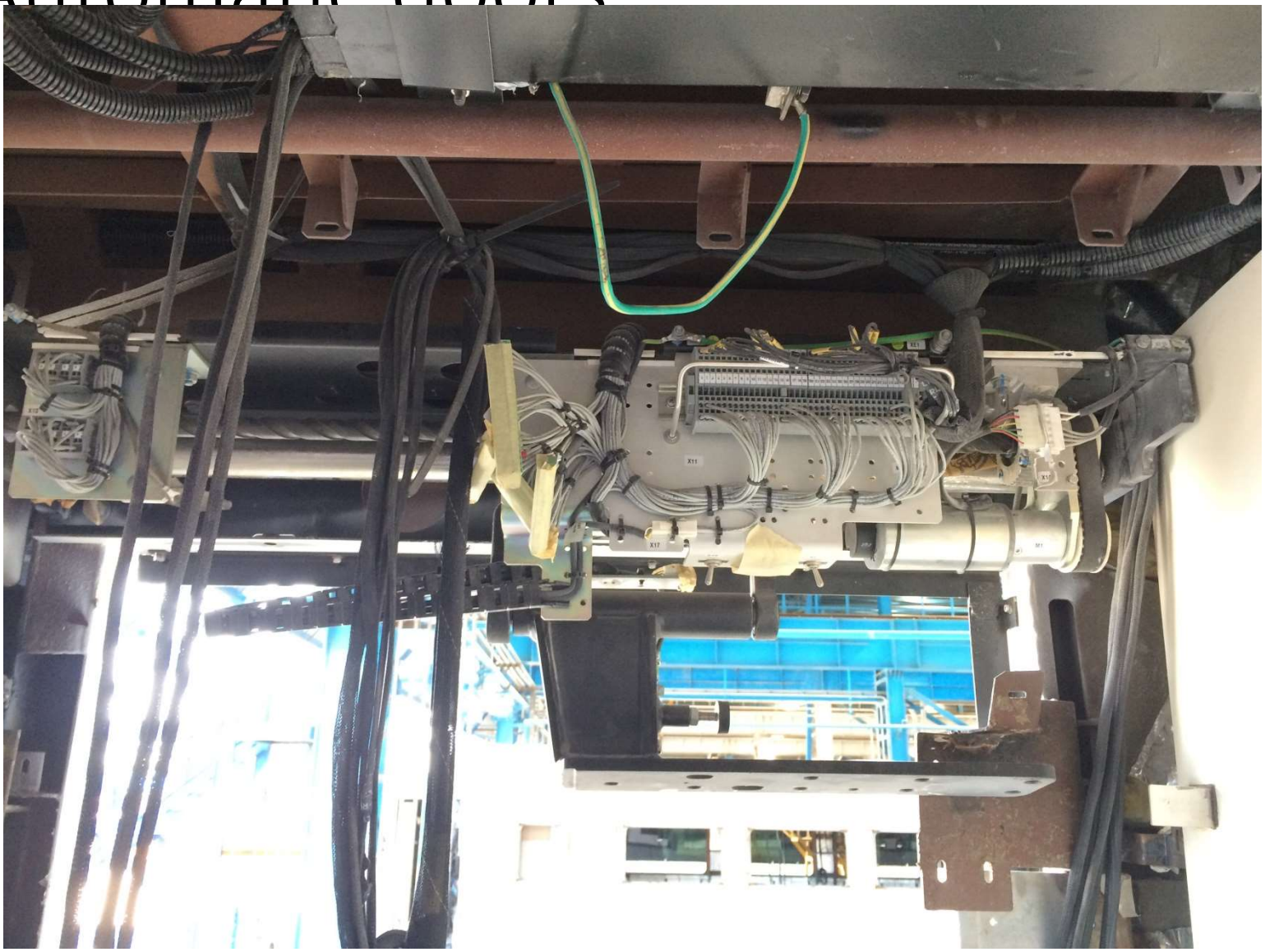
Nose cone



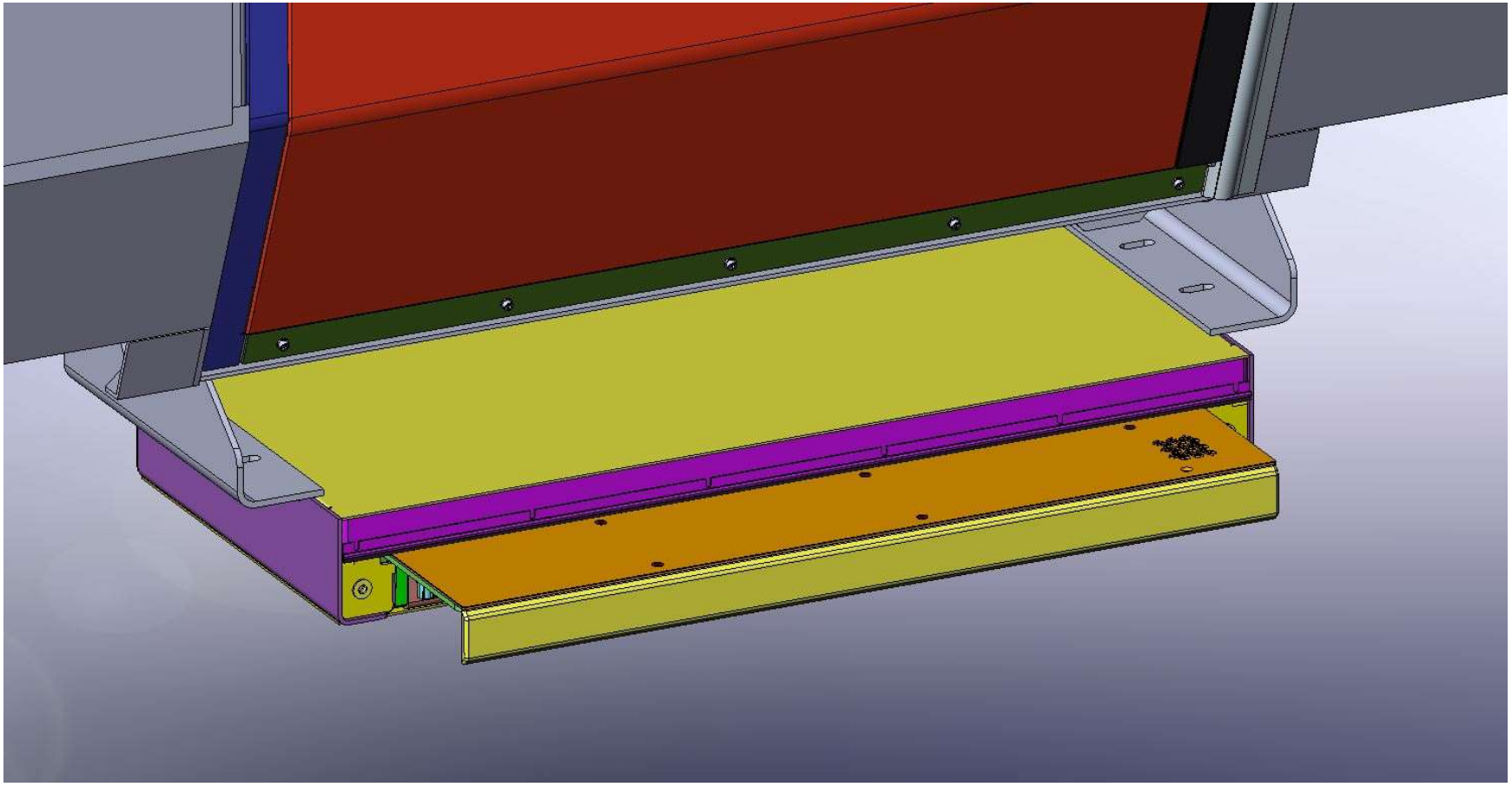
Nose cone

Automatic doors

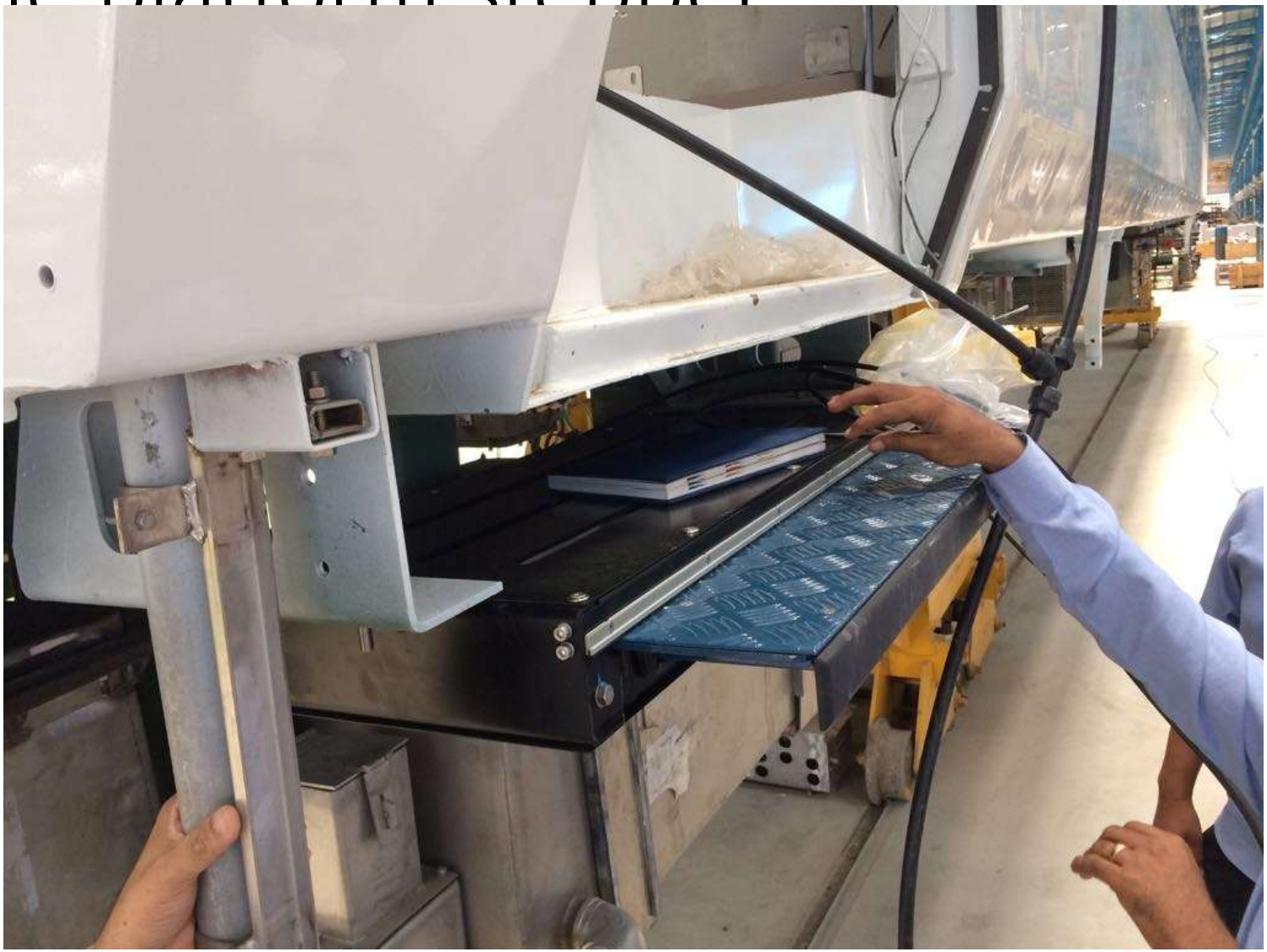
Automatic doors



The platform stepper



The platform stepper



CC – 78 SEATS

Wiring harnesses

a

Wiring harnesses

a

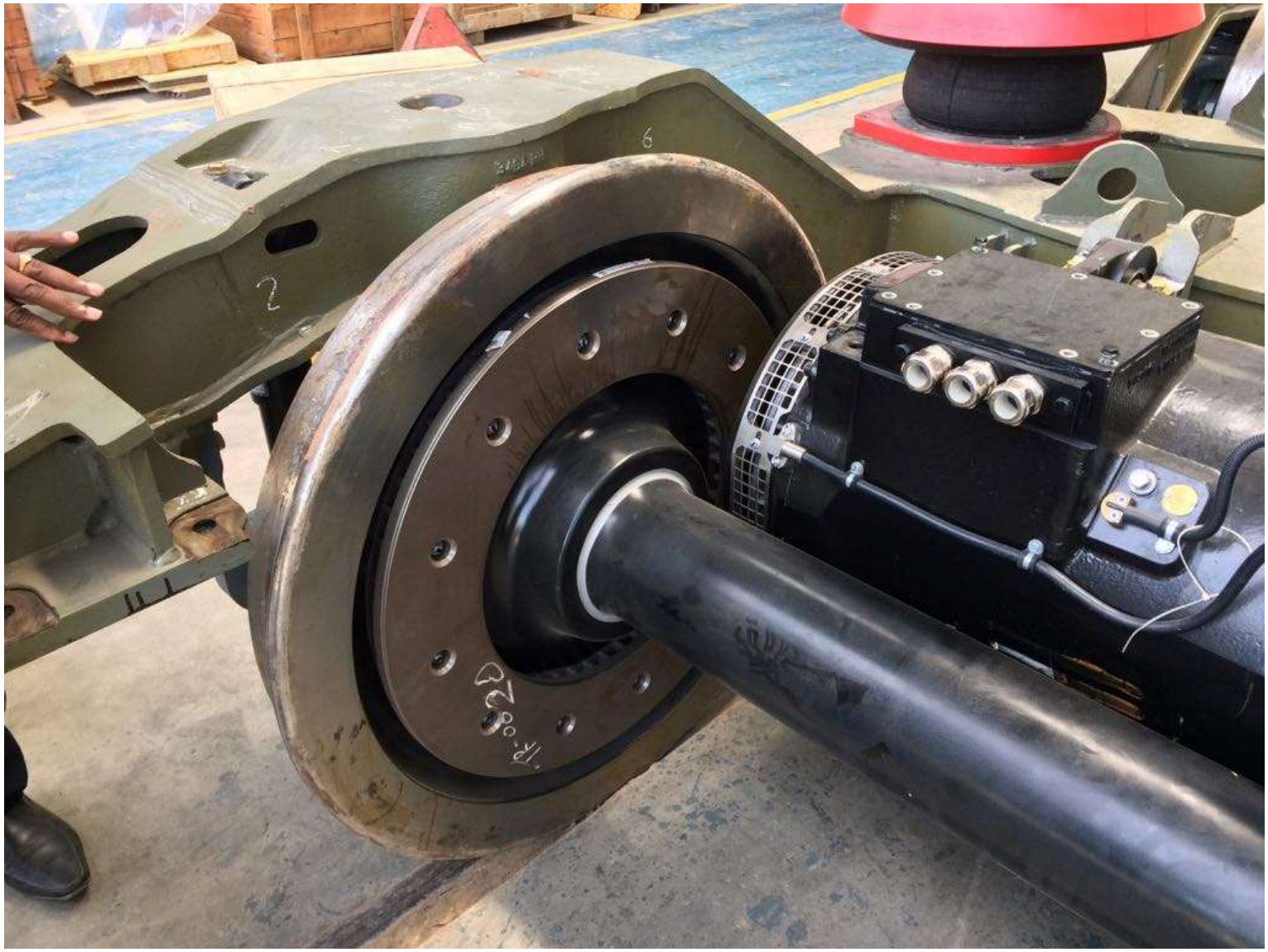
The bogie – fit for 200kmph

Bolsterless, air-suspension, brake disks on wheels

The motorised bogie

Fully suspended motors

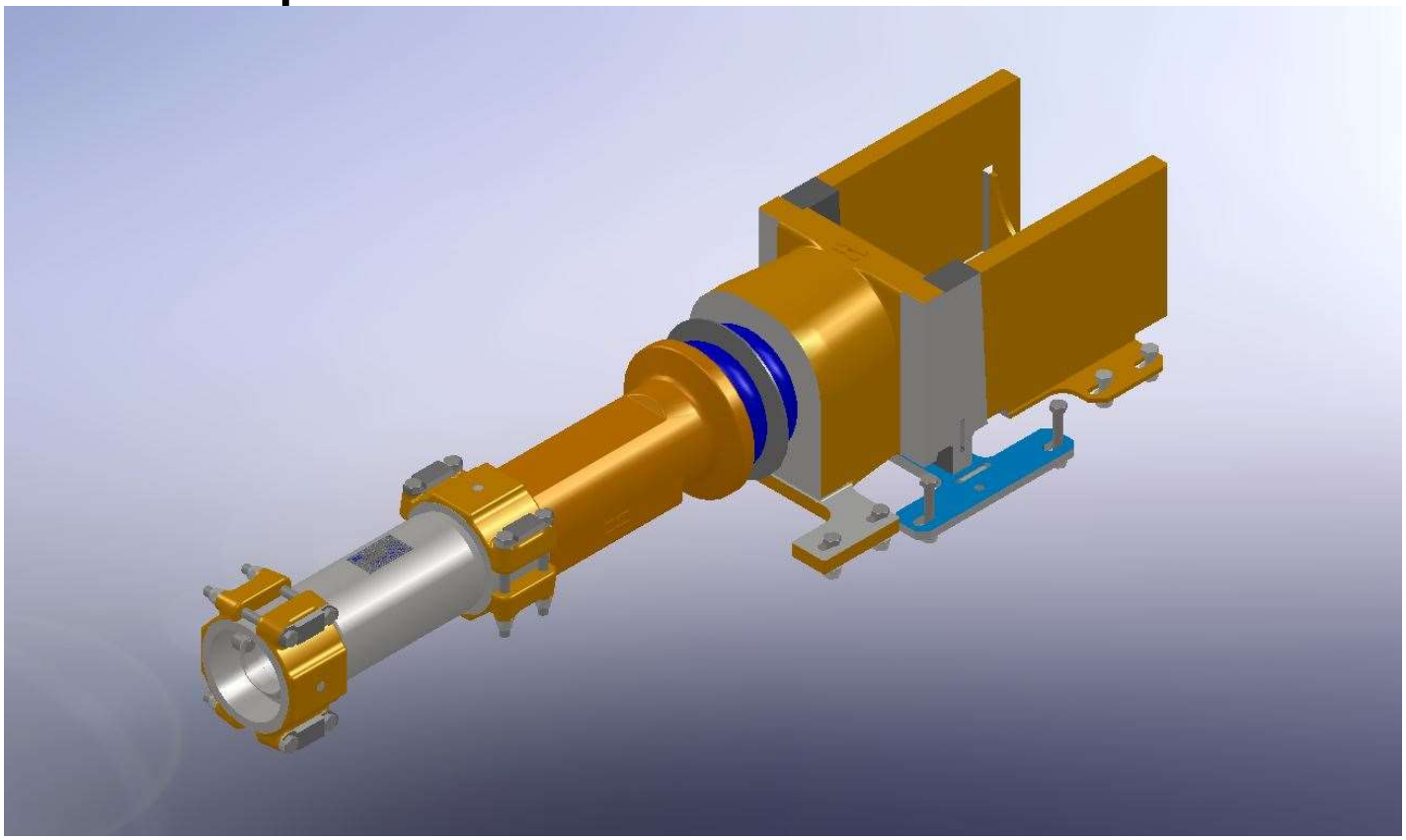
The motorised bogie



Brake Disks

Brake Callipers

The coupler



Jerk free Dellner Coupler

The coupler

Jerk-free Dellner Coupler

The Design

Technology Readiness..

Item	Status
Car body design/manufacture including painting	Not good enough; consultancy needed for design, tooling and supervision of manufacturing
Fully suspended traction motor bogie fit for 180 km/h	consultancy needed for design and validation; sourcing would be possible through select vendors
Modern 3-phase IGBT propulsion	Almost there
TCMS	Almost there
Current technology PIS	Almost there
Smart train concepts	Exploit the capability of IT companies in India with imported hardware
Pleasing & ergonomically designed interiors	Feasible through outsourcing
World-standard toilets	Design and sourcing feasible in india with imported vacuum evac system
Interface with ground infrastructure/cab signaling etc.	Interlinked with developments in infra on IR
Miscellaneous	To be worked out as we move along

Development – Train18 in 18 Months

Flagging off – 26th October'2018

Commissioning – 15th October 2018

First Carbody & Furnishing Start May'2018

Procurement of sub-assemblies – Oct'2017

Carbody Manufacture start Feb'2018

Design Started April '2017

Project Informal Go Ahead – Feb'2017
Multi Disciplinary Team – Mar'2017

Idea – Dec'2016 – Rail Vikas Shivir

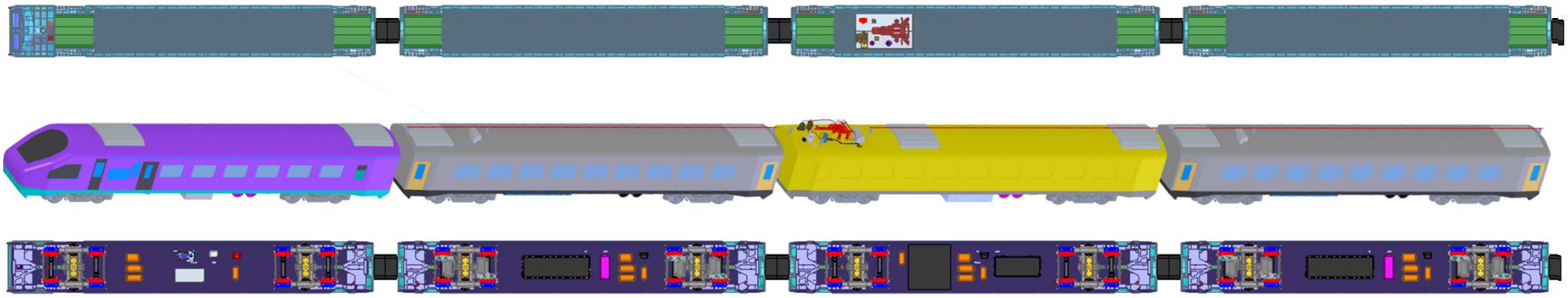
Passenger Capacity

		Class	No.of Seats	No.of Coaches
1	DTC	II	44	2
2	TC	II	78	4
3	MC	II	78	7
4	NDTC	II	78	1
5	NDTC	Exec	52	1
6	MC	Exec	52	1

Architecture

Total 16 Car Formation – 4 X 4 Basic Units

Each Basic Unit with Four Cars



DTC MC TC MC

DTC:
1. Battery
2. Battery charger
3. Compressor

MC:
1. Traction Converter
2. Brake Chopper Resisto

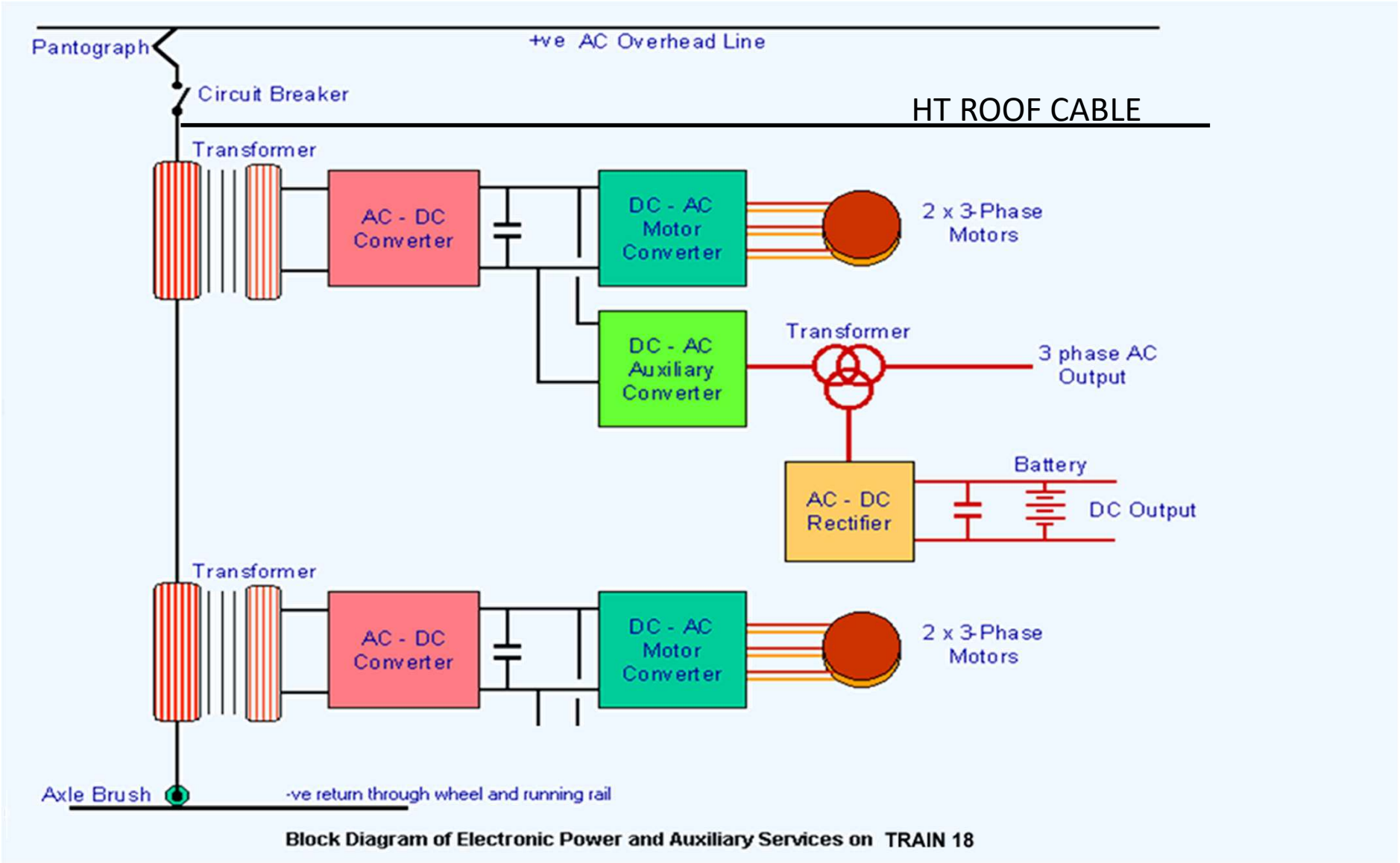
TC:
1. Transformer
2. Aux. Converter
3. Pantograph
4. VCB

MC:
1. Traction Converter
2. Bk Chopper Resisto

Equipment Power

EQUIPMENT	POWER RATING
TRANSFORMER	2500 KVA
TRACTION CONVERTER	550 KW
TRACTION MOTOR	248KW

One Transformer Feeds Two Motor Coaches



Block Diagram of Electronic Power and Auxiliary Services on TRAIN 18

Major design challenges

	Challenge	Action taken
1	Jerks in Tightlock CBC couplers	Semi-permanent head – jerk free
2	Ramp in gangway area	Coupler height reduced to 940mm – Driving ends have coupler height of 1105mm for hauling by Loco
3	Fully sealed double layer gangway needs more end-to-end space	Overall coach length reduced by 440mm (23100 against 23540)
4	Automatic plug door with sliding foot step	Doorway shifted to coach ends to accommodate sliding step
5	Low roof in TC having Pantograph	Sleek AC duct designed for low roof area to maintain head room for luggage rack
6	To reduce the Air Drag and Give Contemporary modern look	Aero-dynamic frontend and Continuous windows
7	Bogie suitable for fully suspended traction motors and disc brake	New generation bogie with wheel mounted brake disc

Advantages

- Improved operational reliability with optimized redundancy and good traction performance
- Low axle load - Less wear and tear
- Effective Adhesion force utilization - High acceleration and deceleration – More Throughput
- Efficient regenerative brake utility -Low energy consumption
- Easy & Low maintenance and good life-cycle-cost - compensation of initial cost by low running cost

Train 2018

SPEED 160 KMPH

GPS based PIS/PAS

ON BOARD INFOTAINMENT

AUTOMATIC PLUG DOORS

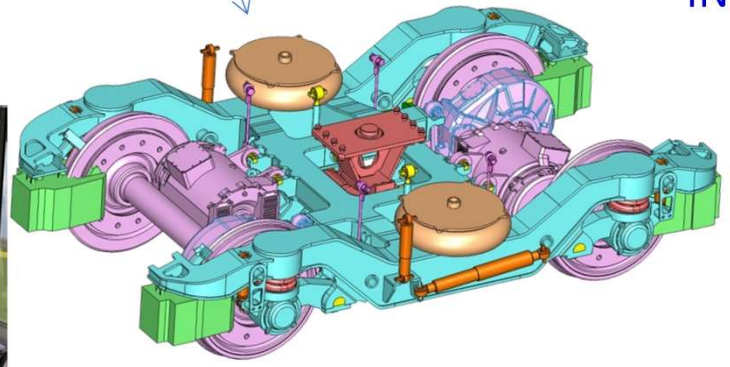
SLIDING STEP

VACCUM TOILETS

COMFORTABLE INTERIORS – DIFFUSED LIGHTING

QUICK ACCELERATION

UNDERSLUNG PROPULSION



LATEST GENERATION BOGIES FOR BETTER RIDING COMFORT

SEALED GANGWAYS

Train 18
16 Car train set

GPS BASED
PIS/PAS

ON BOARD
INFOTAINMENT

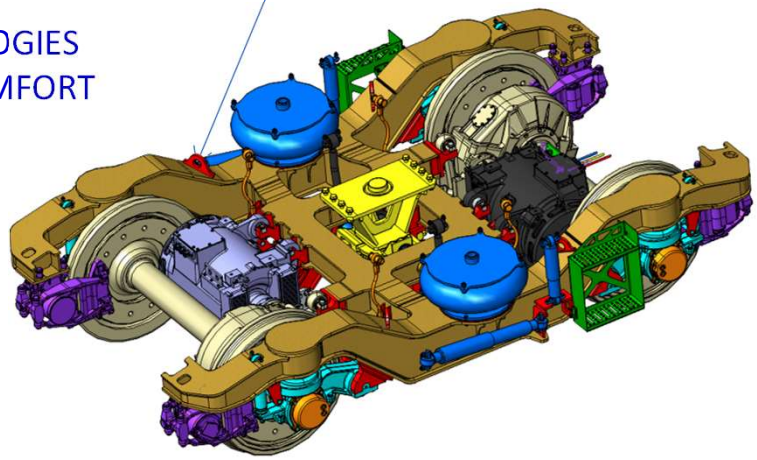
VACCUM TOILETS

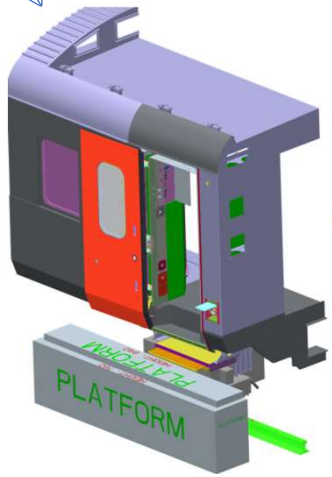
QUICK ACCELERATION

UNDERSLUNG
PROPULSION

COMFORTABLE INTERIORS –
DIFFUSED LIGHTING

LATEST GENERATION BOGIES
FOR BETTER RIDING COMFORT



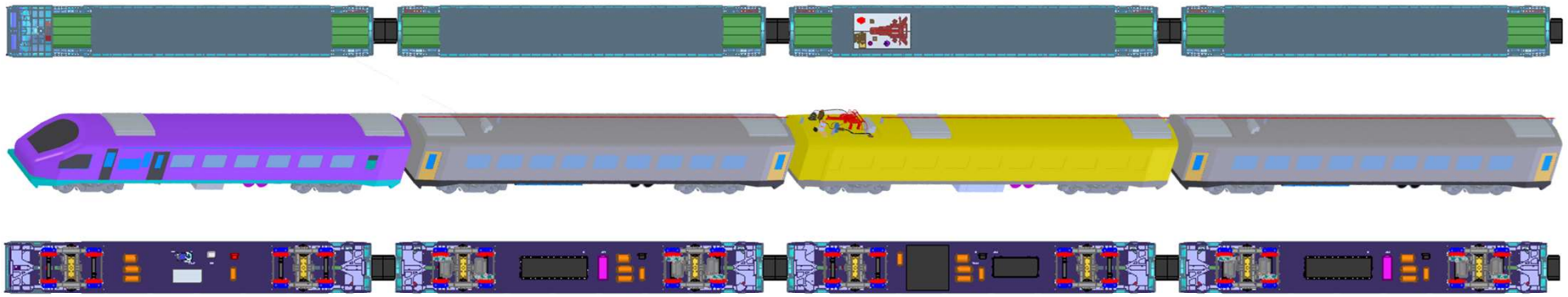


AUTOMATIC DOORS &
FOOTSTEPS

Architecture of Train 18

Total 16 Car Formation – 4 X 4 Basic Units

Each Basic Unit with Four Cars



DTC MC TC MC

DTC:
1. Battery
2. Battery charger
3. Compressor

MC:
1. Traction Converter
2. Brake Chopper Resistor

TC:
1. Transformer
2. Auxiliary Converter
3. Pantograph
4. VCB

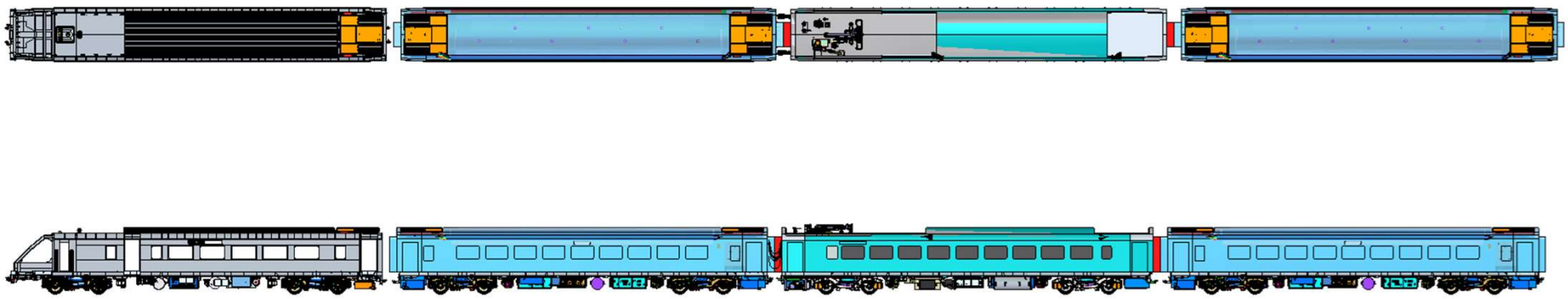
MC:
1. Traction Converter
2. Brake Chopper Resisto

Total 16 Car Formation – 4 X 4 Basic Units

Each Basic Unit with Four Cars

END BASIC UNIT

DTC MC TC MC



DTC:
1. Battery
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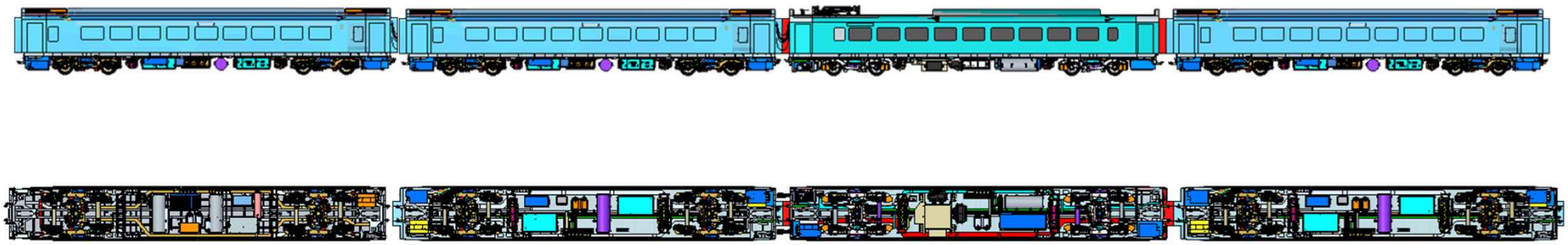
MC:
1. Traction Converter
2. Brake Chopper Resistor

TC:
1. Transformer
2. Auxiliary Converter
3. Pantograph
4. VCB

MC:
1. Traction Converter
2. Brake Chopper Resistor

MIDDLE BASIC UNIT

NDTC MC TC MC



NDTC:

1. Battery
2. Battery charger
3. Compressor

MC:

1. Traction Converter
2. Brake Chopper Resistor

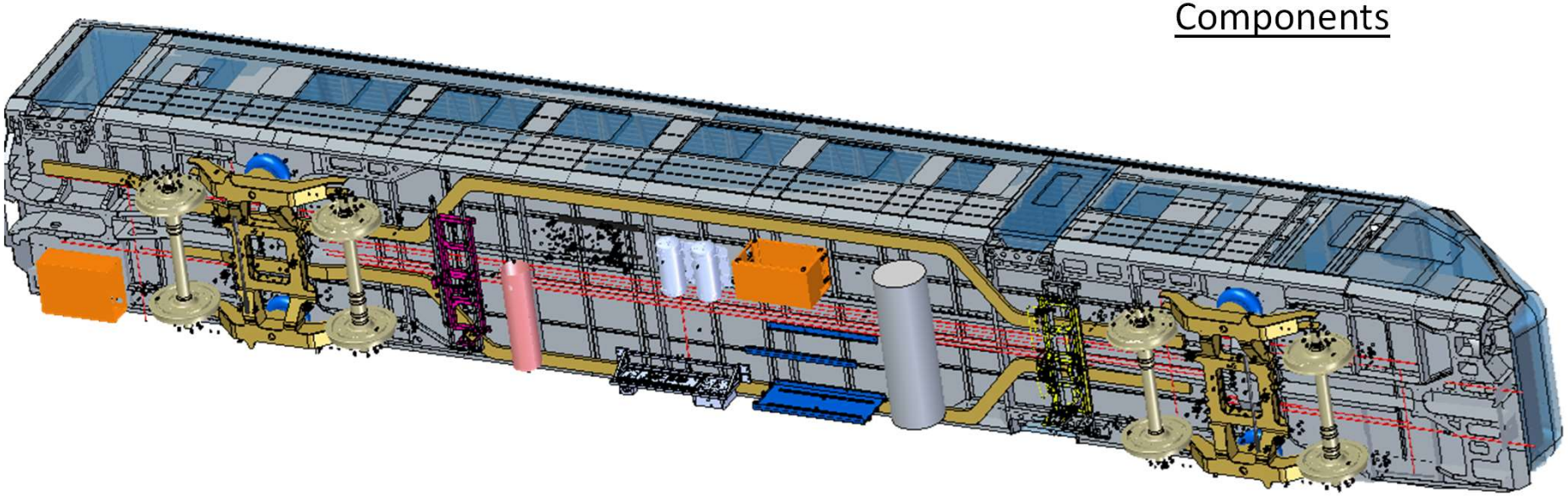
TC:

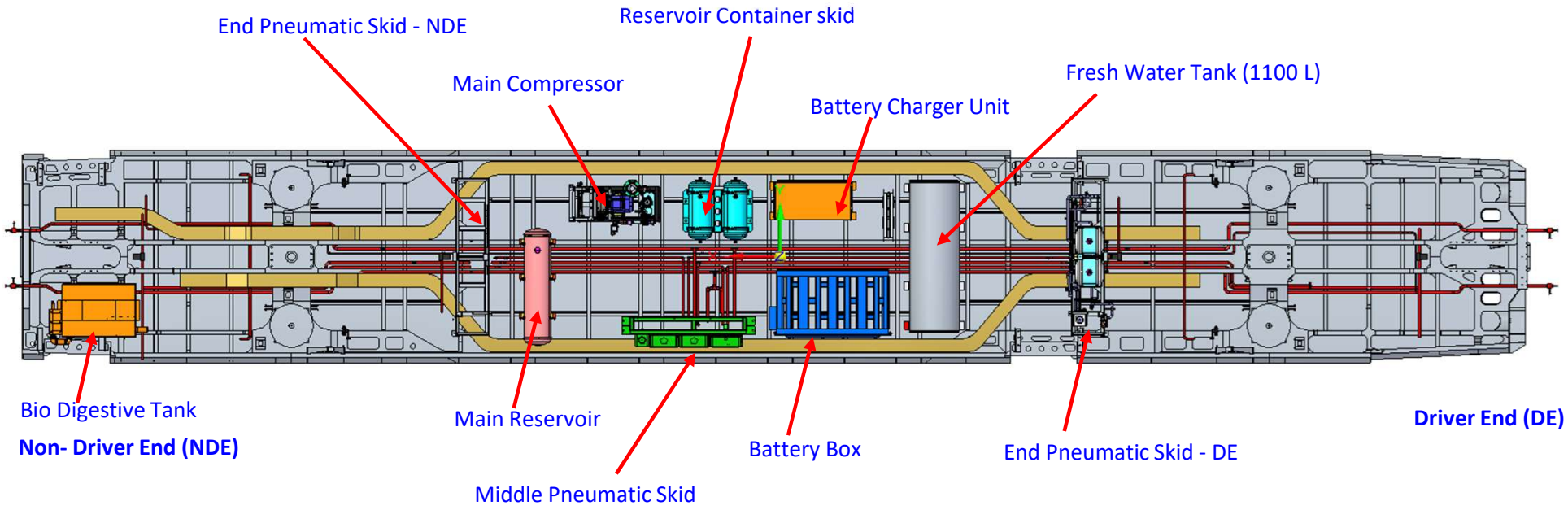
1. Transformer
2. Auxiliary Converter
3. Pantograph
4. VCB

MC:

1. Traction Converter
2. Brake Chopper Resistor

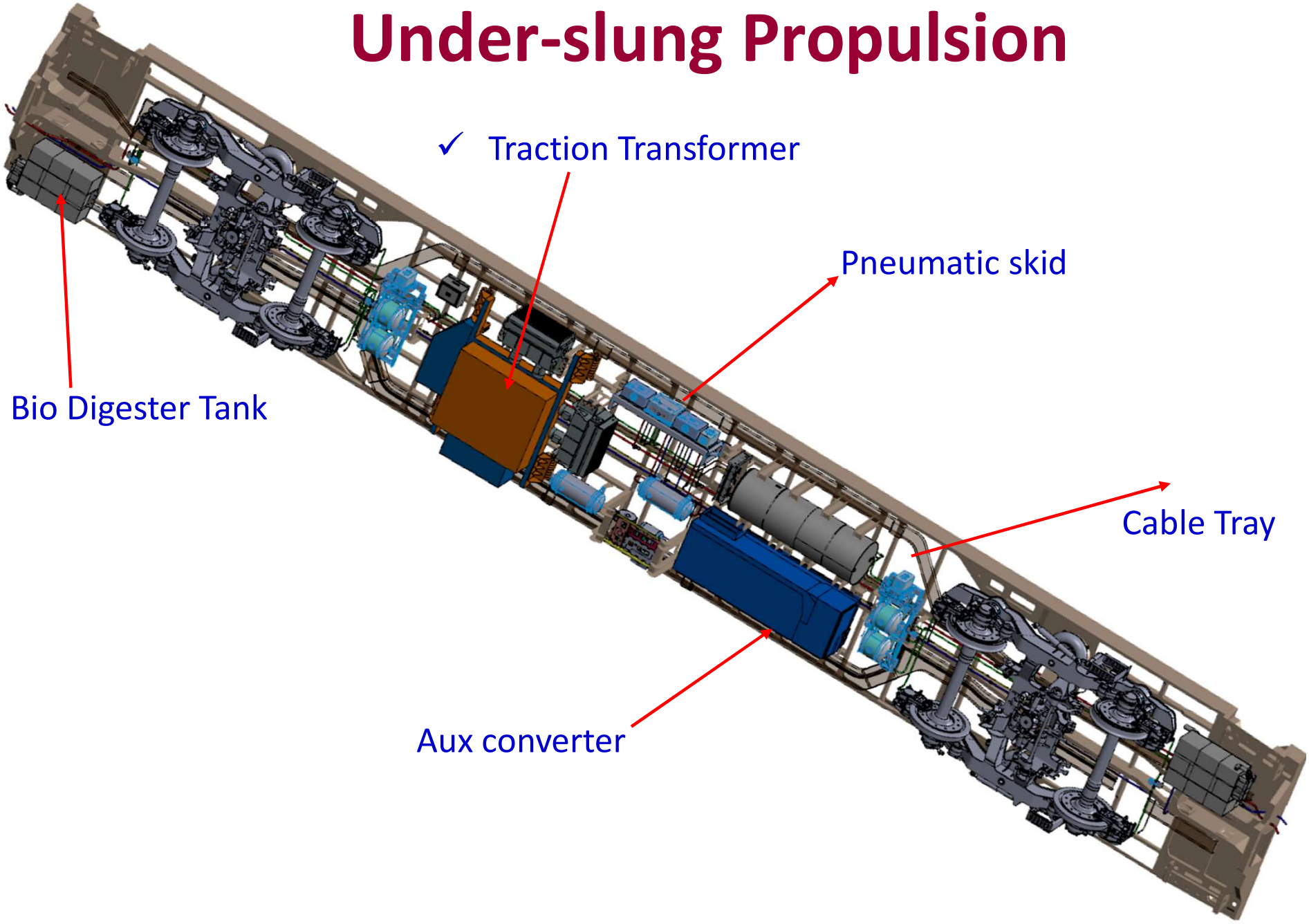
DTC Underslung Components



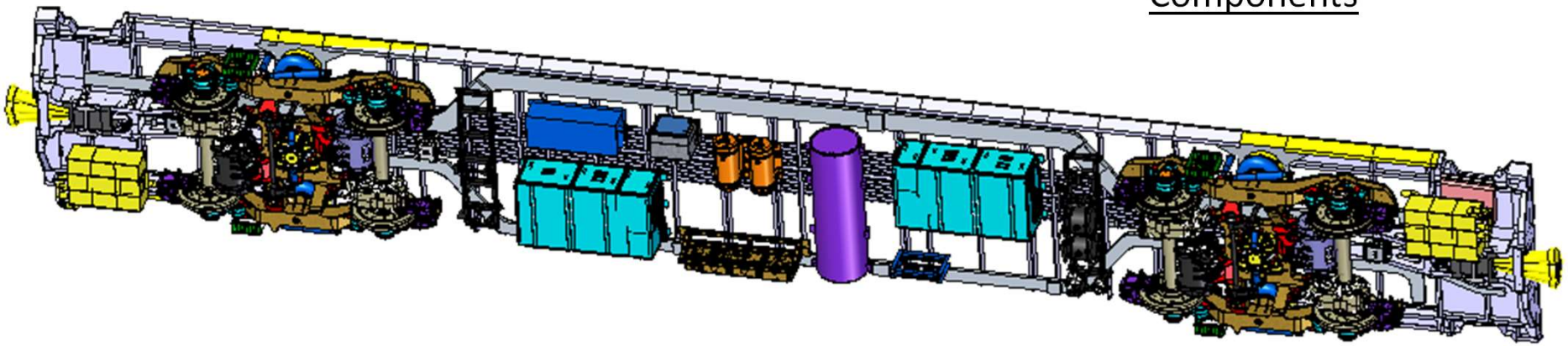


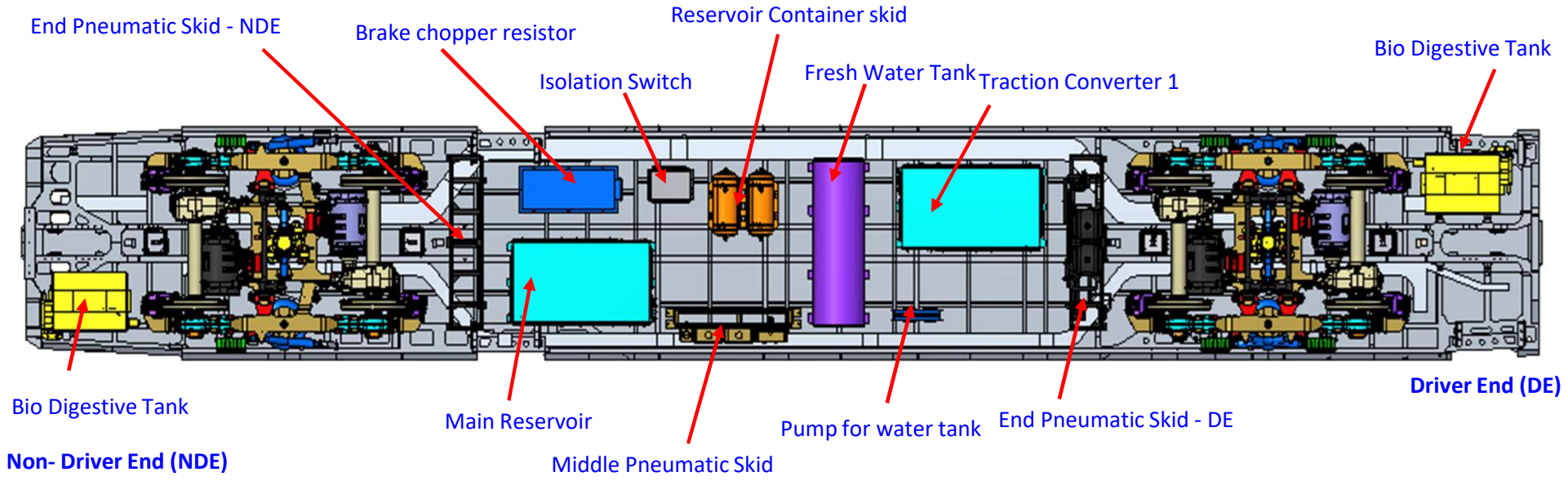
DTC - Bottom View - Equipments

Under-slung Propulsion



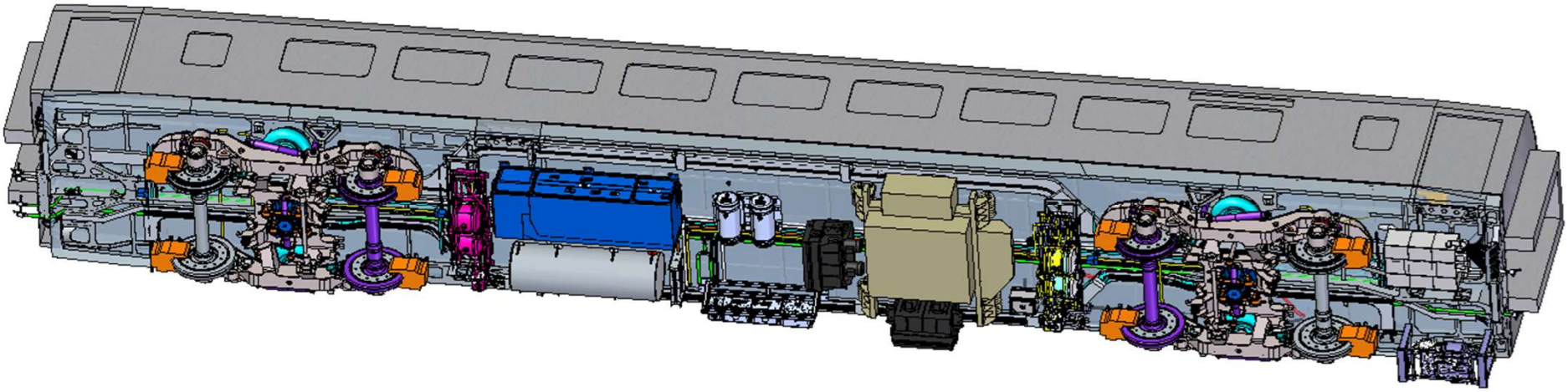
MC Underslung Components

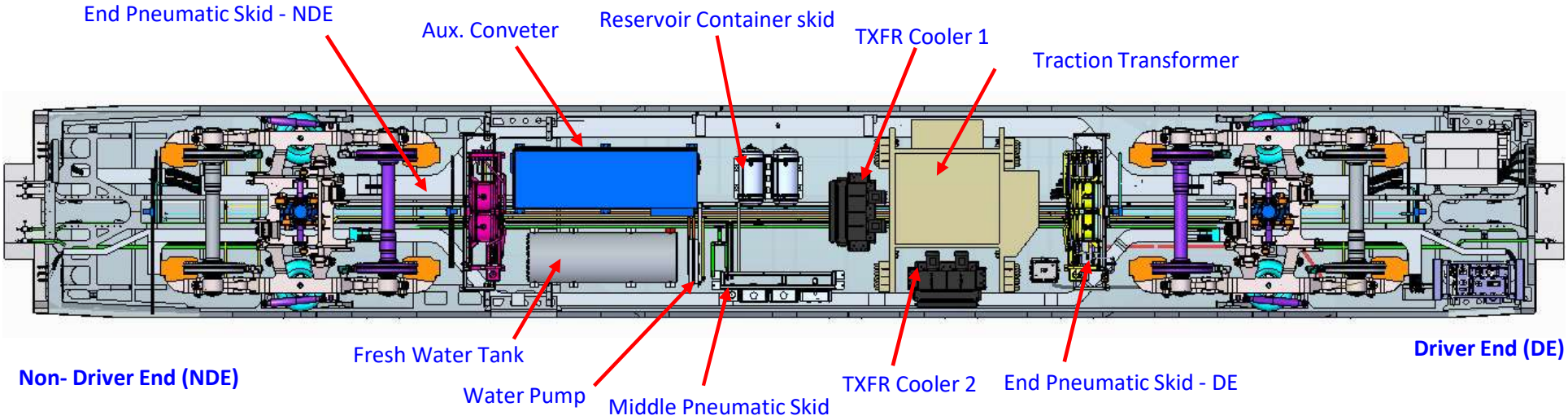




MC - Bottom View - Equipments

TC Underslung Components





MC - Bottom View - Equipments

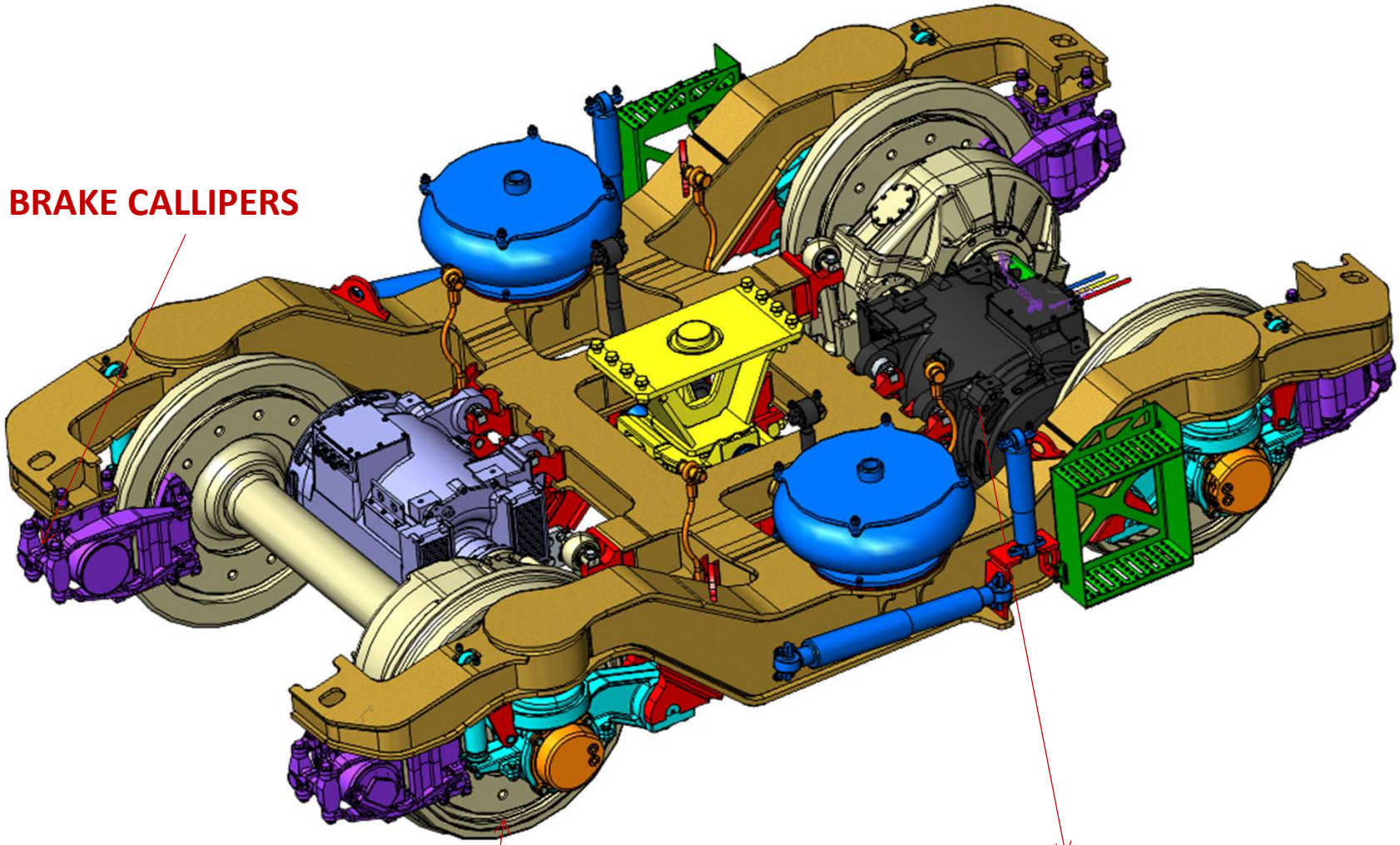
Bolster Less Bogie with Fully Suspended Traction Motors

- ✓ Reduced weight (Reduced Unsprung Mass)
- ✓ Better Ride Comfort
- ✓ Reduced number of Wearing Parts
- ✓ Greater Stability at higher speeds (Because of Yaw dampers and rigidity of rubber items)
- ✓ Better performance on curves

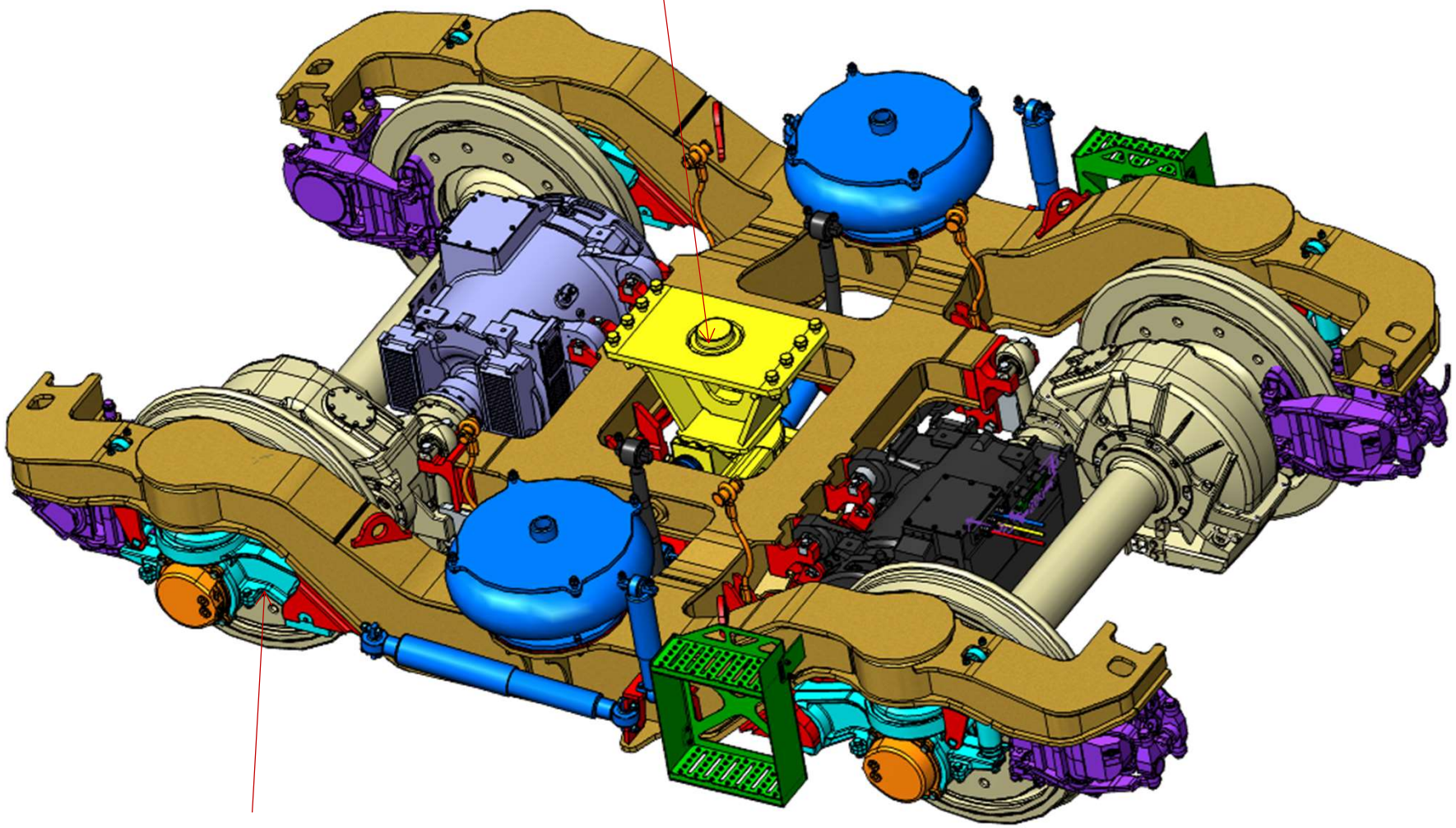
EP Brake System with Latest Gen Electronic Platform

- ✓ Bogie level control of Brakes and Two Tier Redundancy of Mechanical and Electronic equipment
- ✓ Wheel Slide Control and Jerk Control
- ✓ Quicker application and release (Lesser Brake distances)
- ✓ Perfect blending of Regenerative and Mechanical braking
- ✓ Oil free Compressors

BOLSTER LESS DESIGN

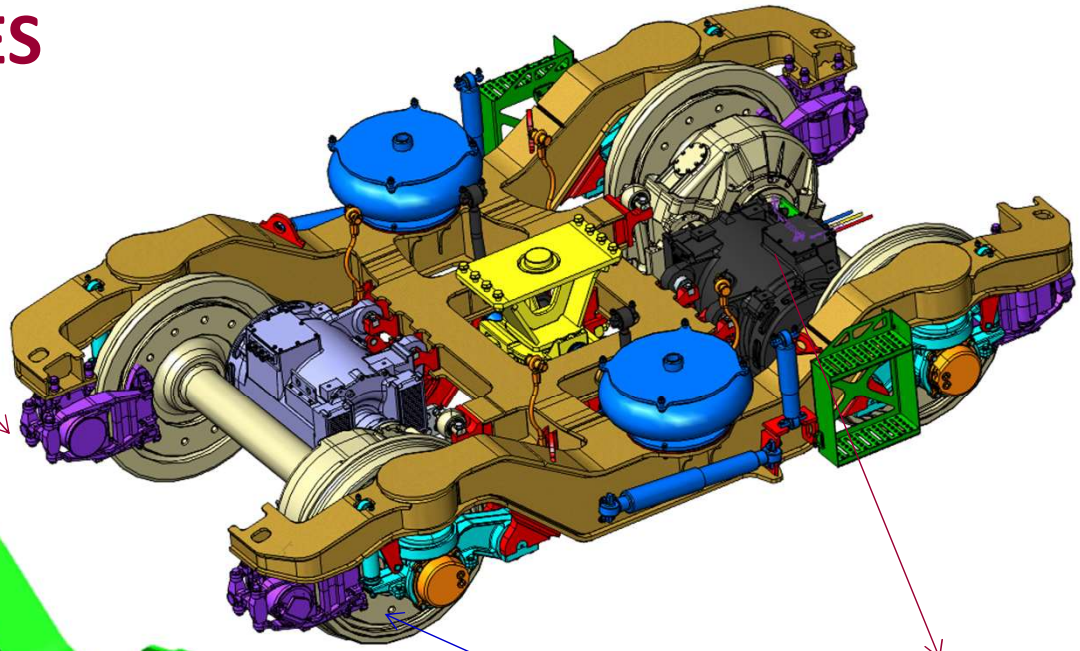


CENTER PIVOT



CONTROL ARM & PRIMARY SPRING

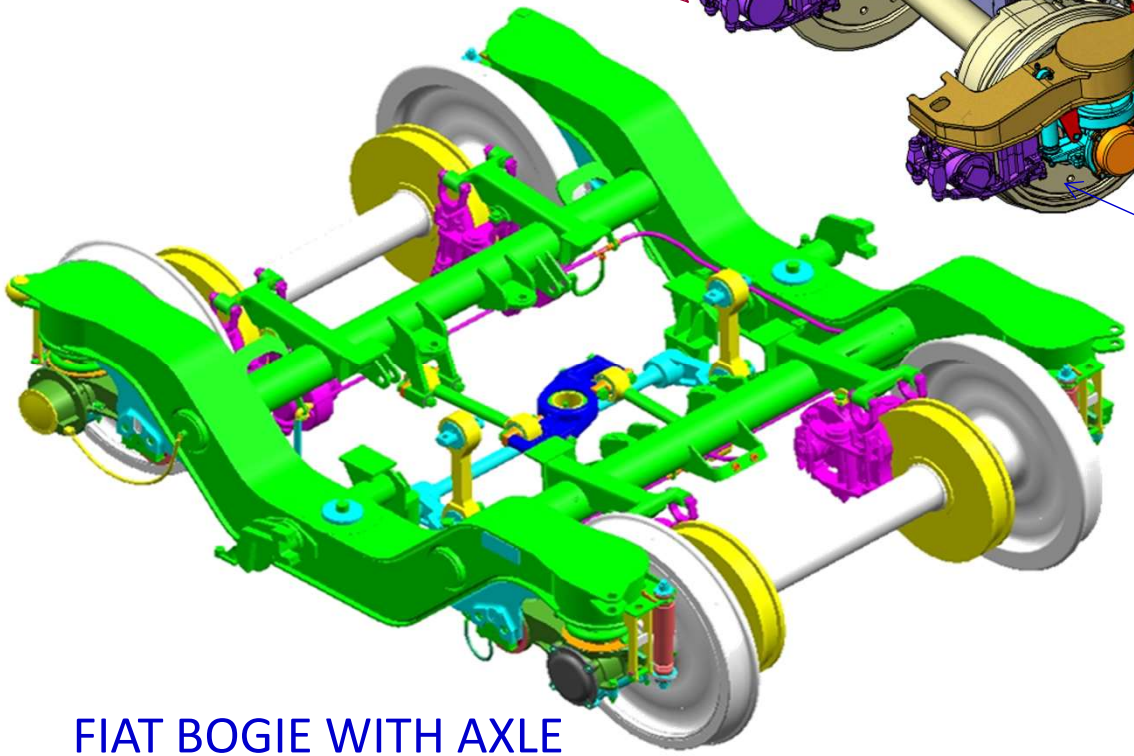
WHEEL MOUNTED BRAKE DISC ON MOTOR AS WELL AS TRAILER COACHES



BRAKE CALLIPERS

FULLY SUSPENDED TRACTION MOTOR

WHEEL MOUNTED BRAKE DISC



FIAT BOGIE WITH AXLE MOUNTED DISC BRAKES

Brake Callipers

Train-18 Bogie

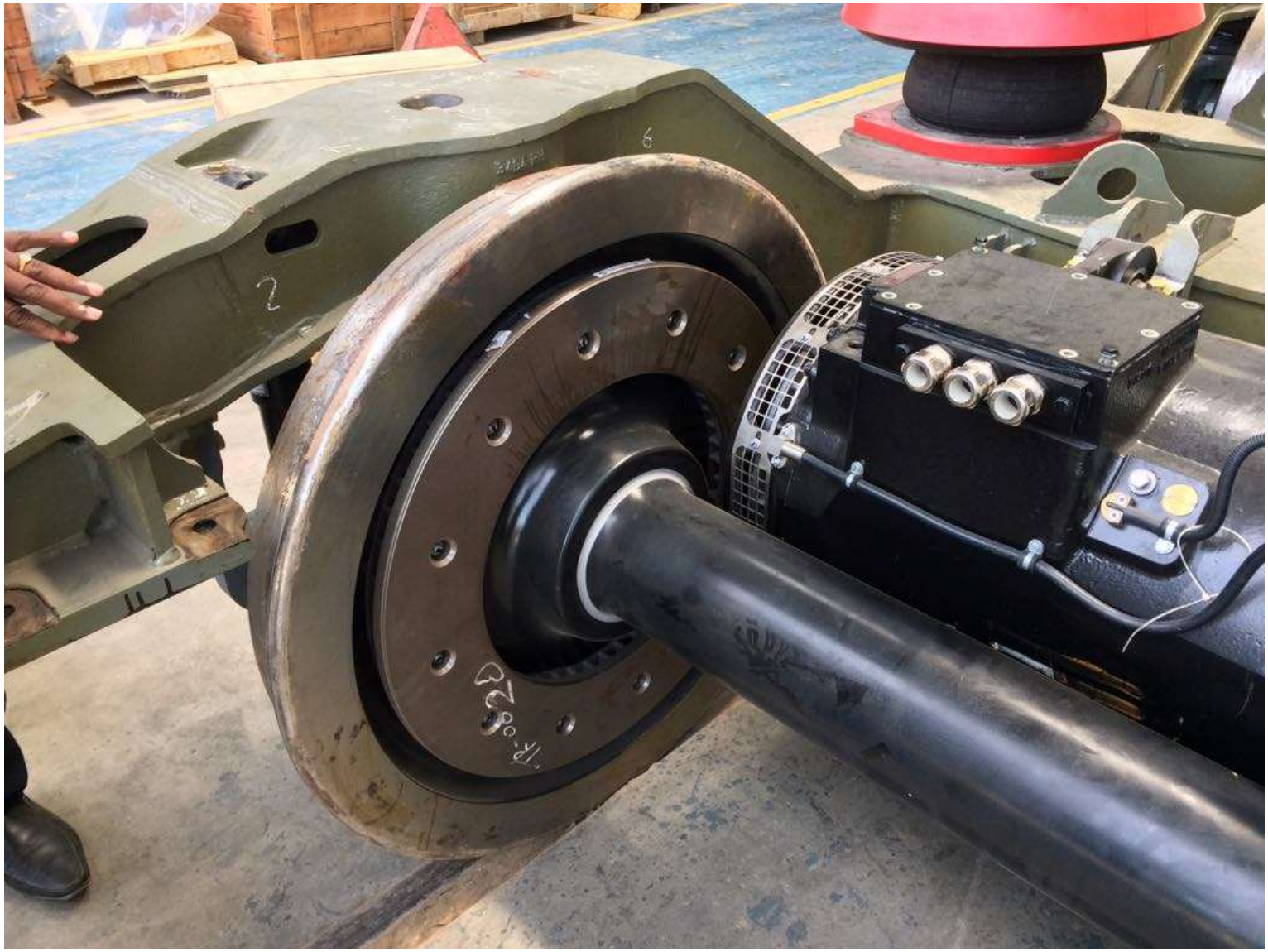
The bogie – fit for 200kmph

Bolsterless, air-suspension, brake disks on wheels

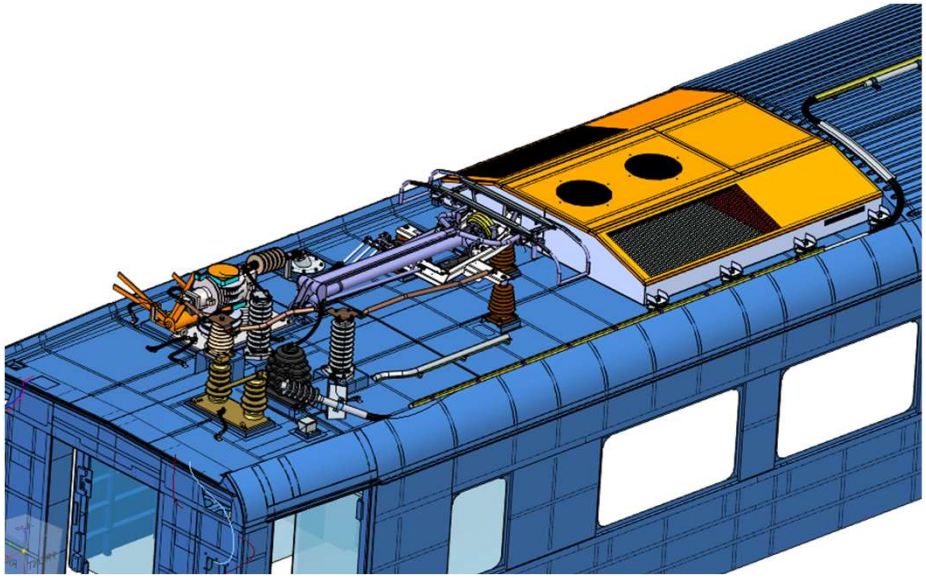
The motorised bogie

Fully suspended motors

The motorised bogie

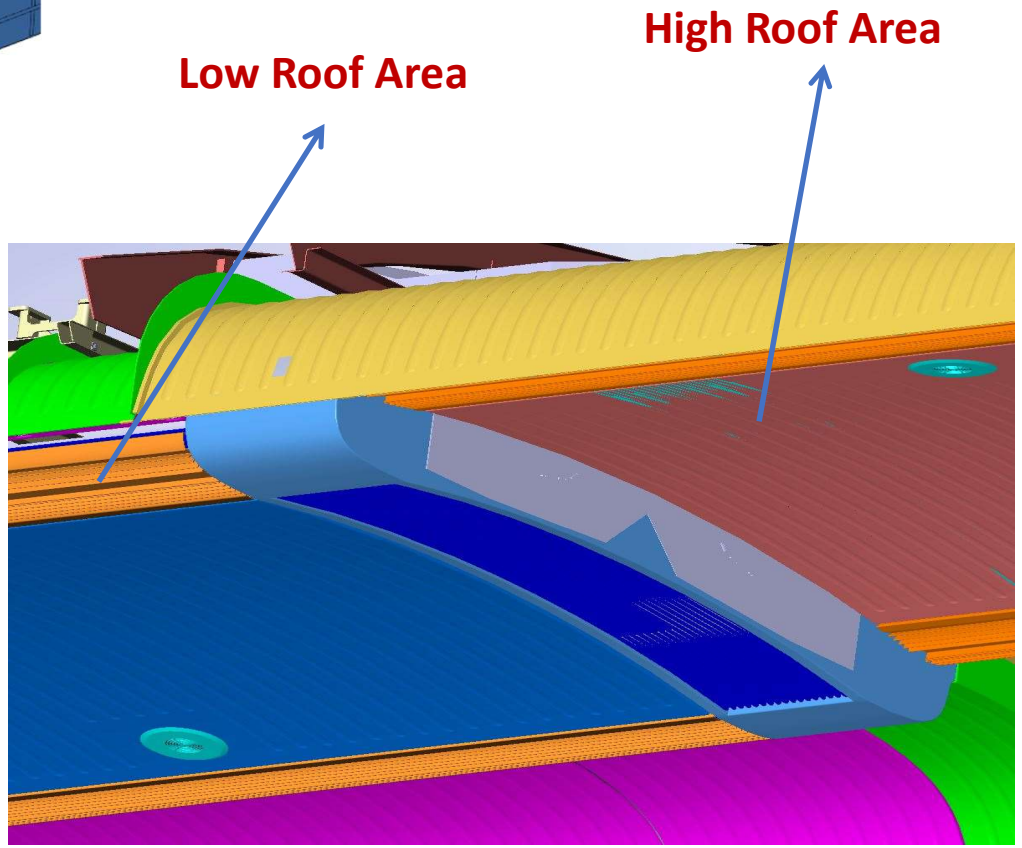


Brake Disks

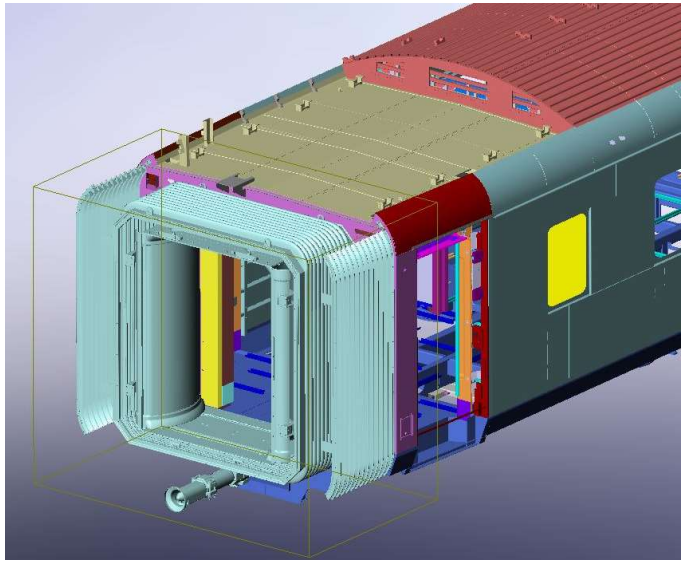


Low Roof
In Pantograph Coach

- ✓ Low Head Room Below Pantograph
- ✓ Not feasible to extend the AC duct and also the diffuser element will be not sufficient to provide conditioned Air to low roof area



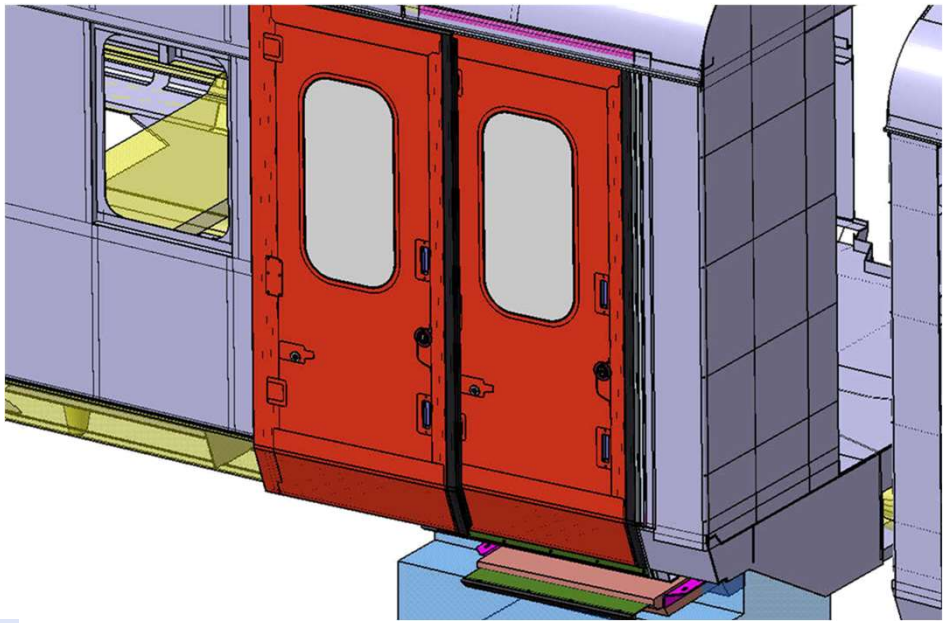
Choice Of Gangway

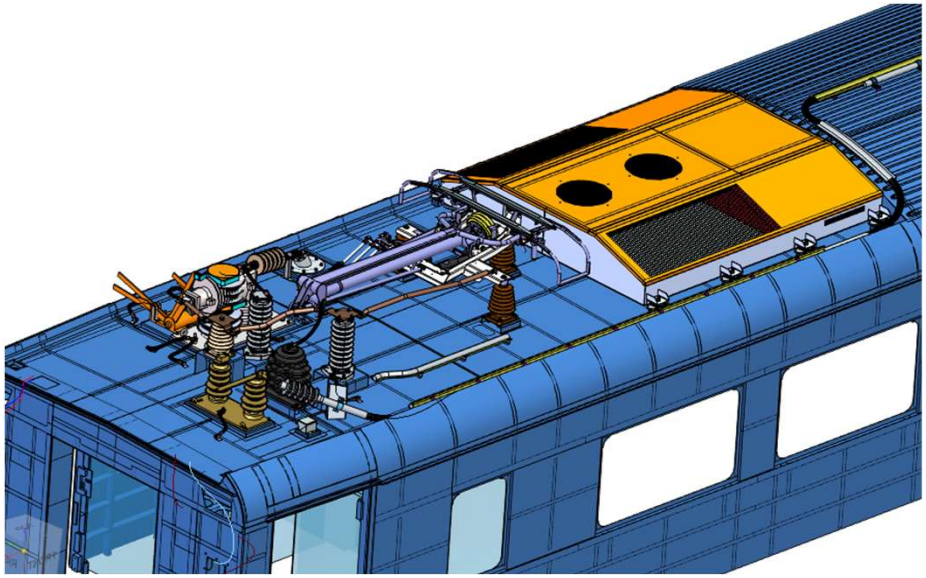


- ✓ Simple Fully Sealed Gangway Vs Fully Sealed Gangways with Inner and Exterior Fairings
- ✓ For contemporary exterior look as well as for free passenger movement – Gangway with exterior and interior fairings was chosen
- ✓ Mounting of exterior fairing required iterations of changes in Inter Vehicular Electrical Couplers and Roof HT Cable

Automatic Plug Doors with Sliding Foot Steps

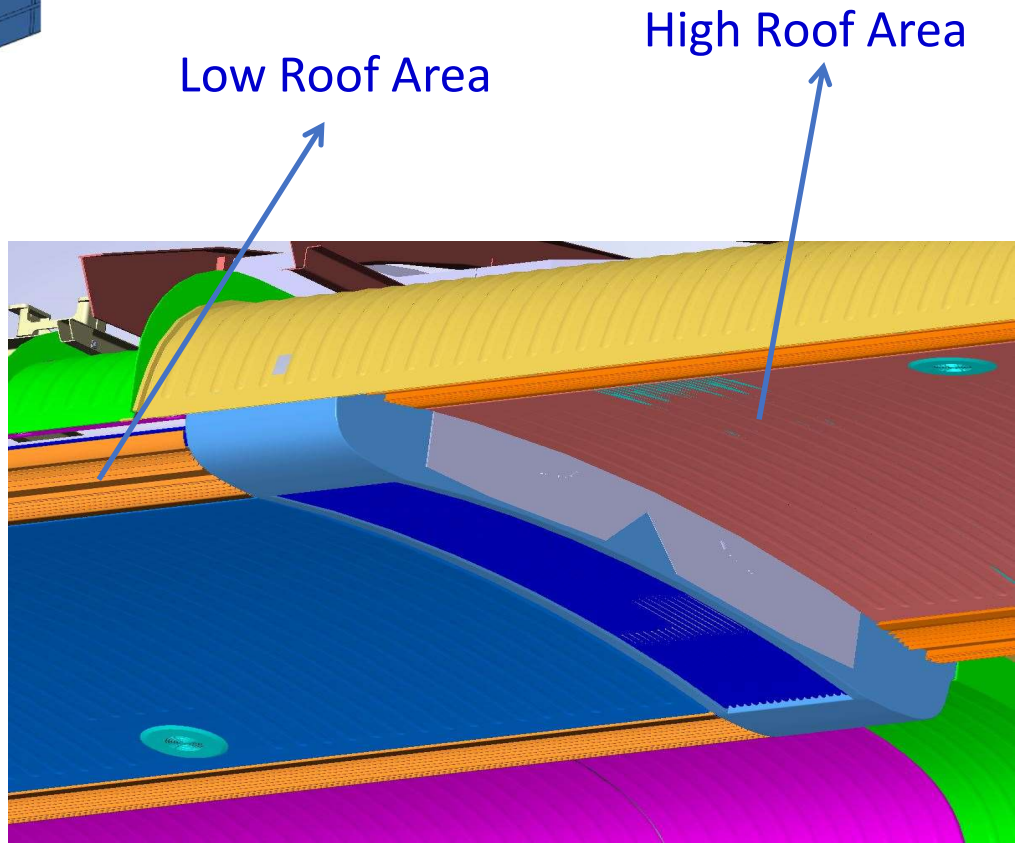
- ✓ Provision of Sliding Step Required shifting of door way to the end – to avoid infringement with Bogie



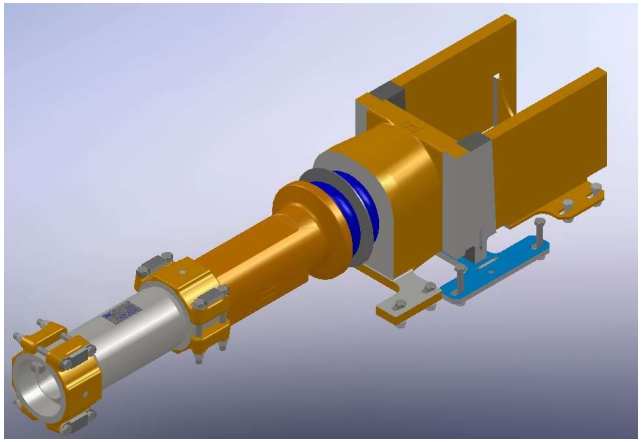


Air Conditioning In Pantograph Coach

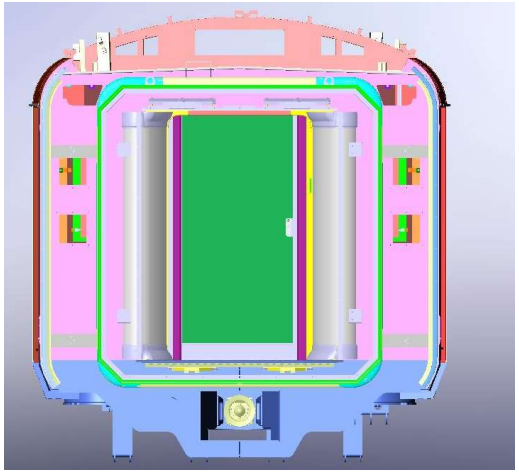
- ✓ Low Head Room Below Pantograph
- ✓ Not feasible to extend the AC duct and also the diffuser element will be not sufficient to provide conditioned Air to low roof area

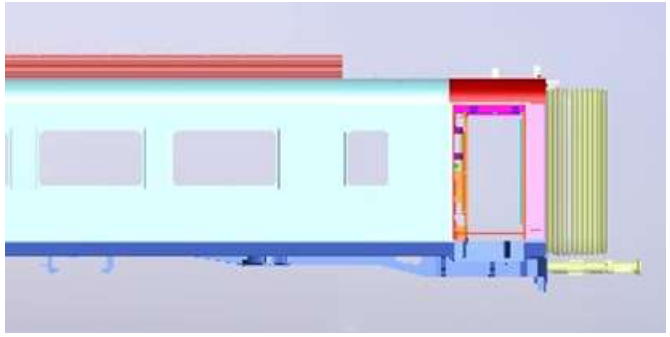


Choice Of Coupler



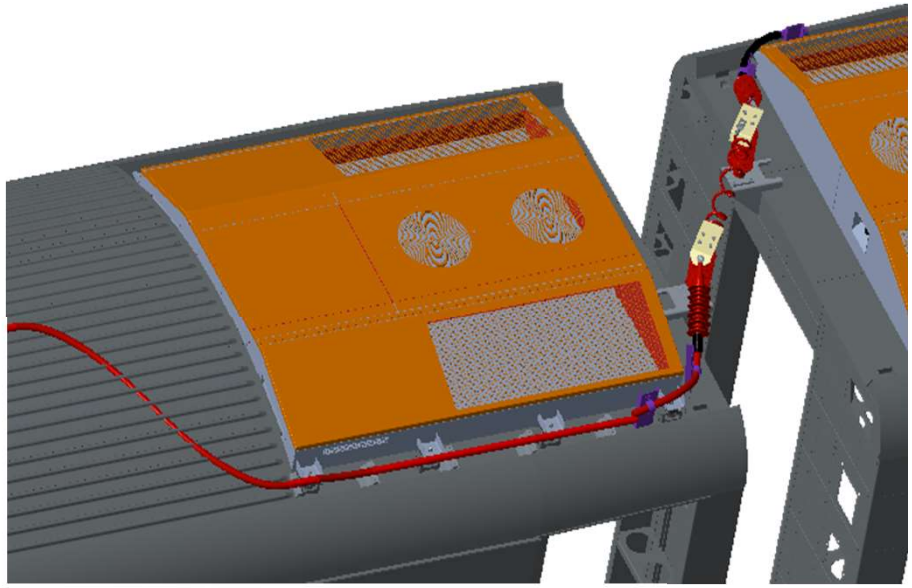
CBC Draft Gear with Semi Permanent Head

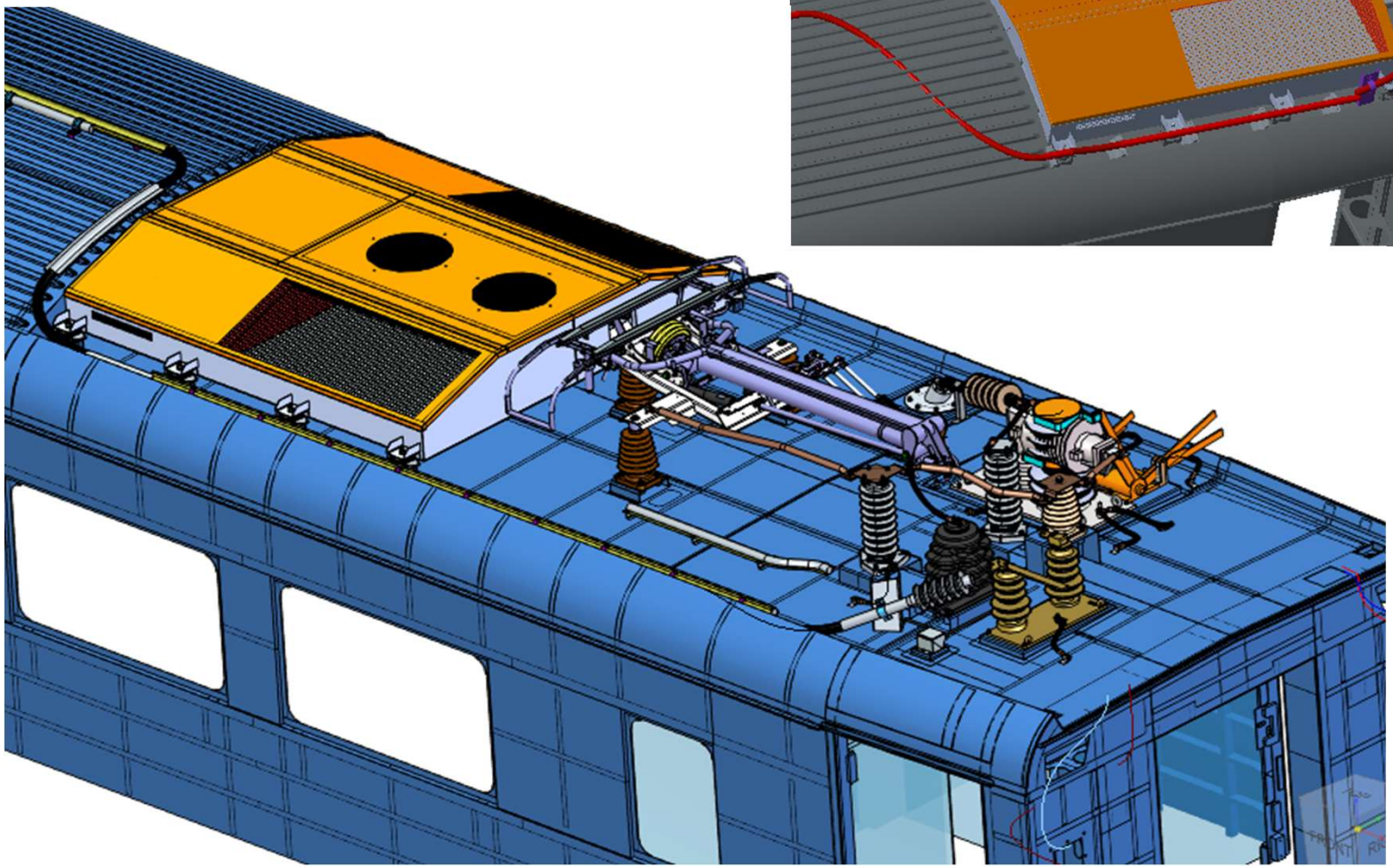


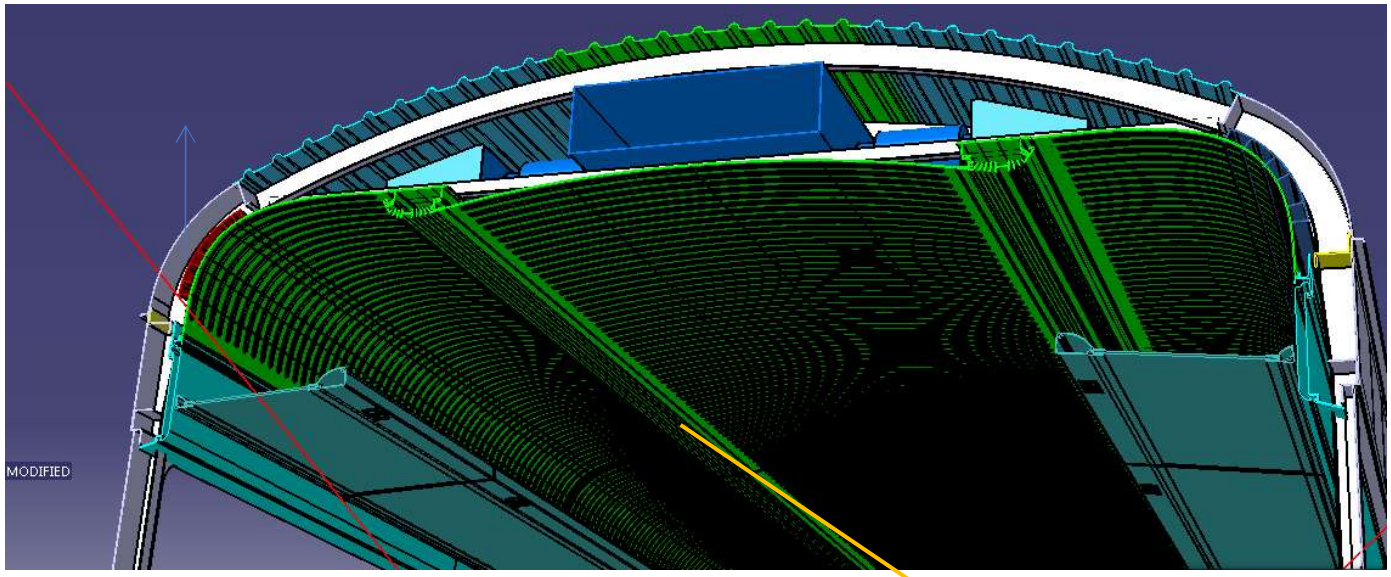


- Tight Lock CBC couplers on Passenger Coaches – where jerks are experienced
- Semi Permanent Couplers between Coaches
- In search for Semi Permanent coupler to haul 24 Coaches, ICF zeroed on CBC draft gear with Semi Permanent Head
- The Coupler is developed by M/s Dellner
- To Mount the Fully sealed gangway at the same height of the coach floor (at 1320 mm from rail level), the coupler height has been reduced to 940mm from 1105 mm.
- This required modification of Coupler pocket on the coach

ROOF HT CABLE

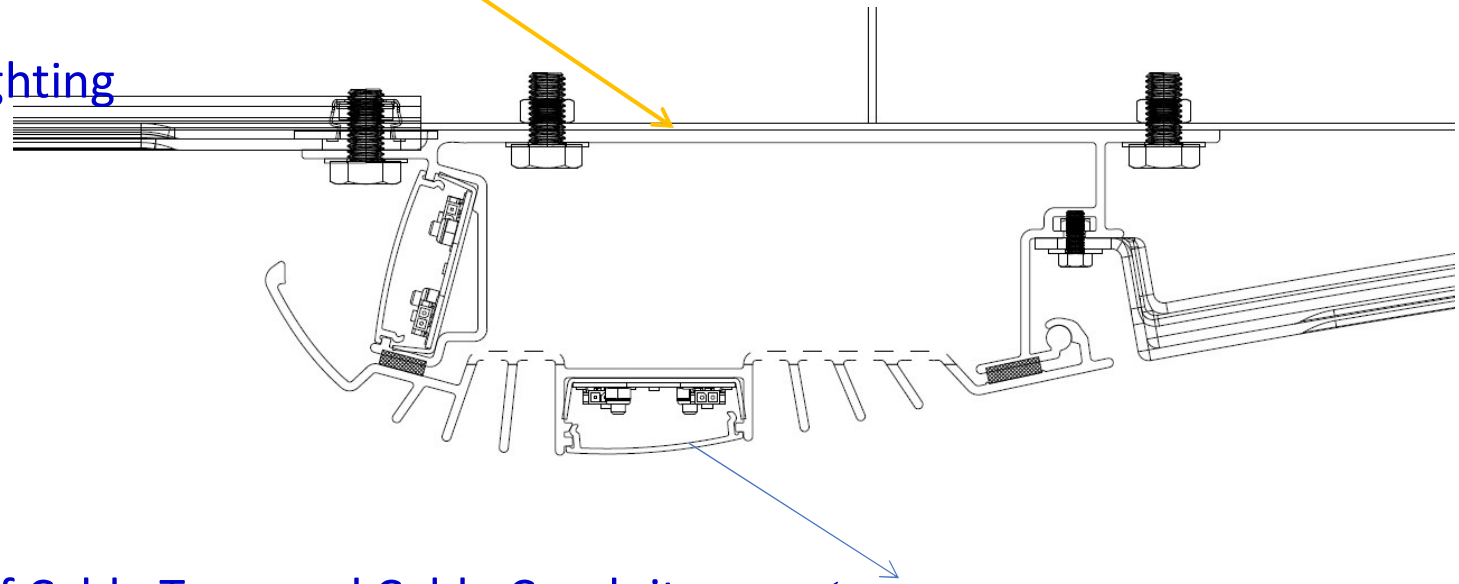






- ✓ Interior Furnishing
- ✓ Design built up

- ✓ LED Diffused Lighting



- ✓ Integration of Cable Trays and Cable Conduits
- ✓ Wider AC Ducting for improvised Flow
- ✓ Direct and Diffused LIghting

- ✓ LED Direct Lighting

Continuous LED LIGHTING

Concealed Roller Blinds

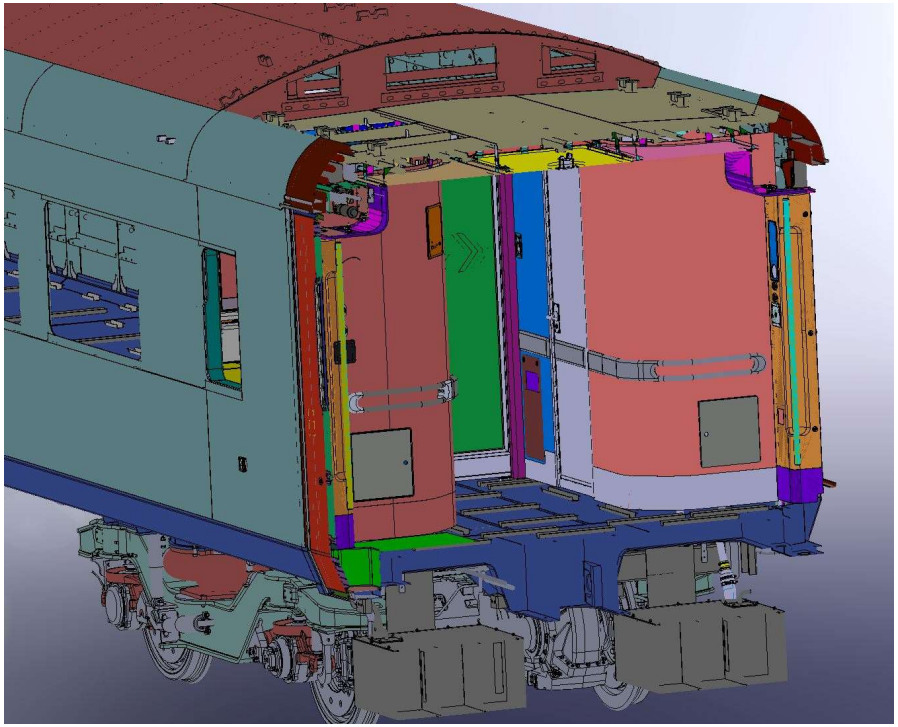
Halogen Free Rubber-On-Rubber Flooring

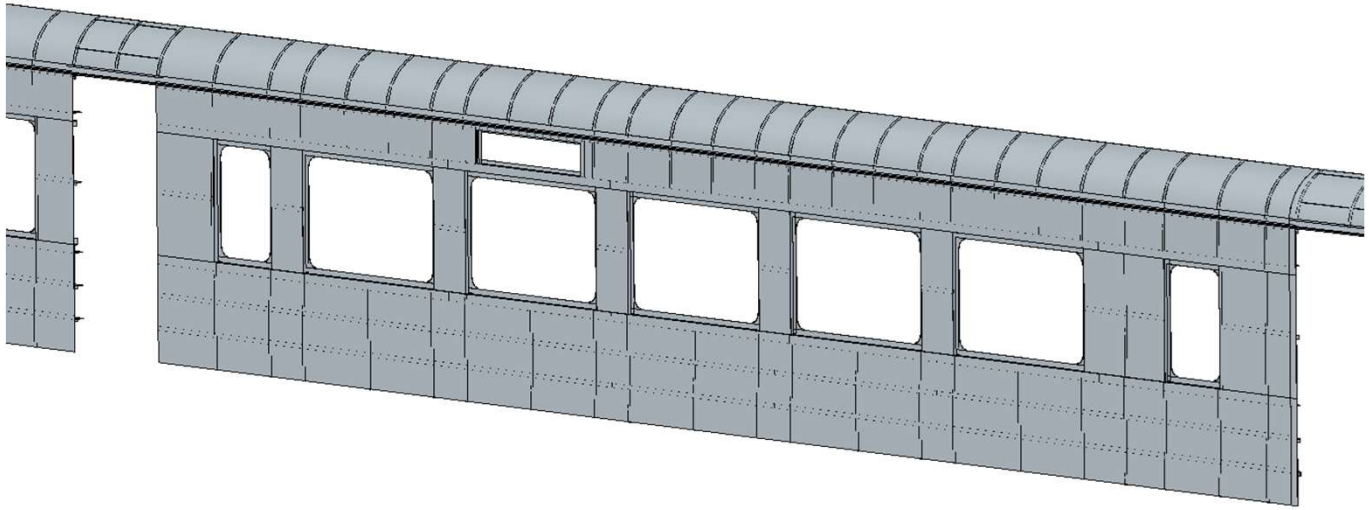
Full Lighting

Diffused Lighting

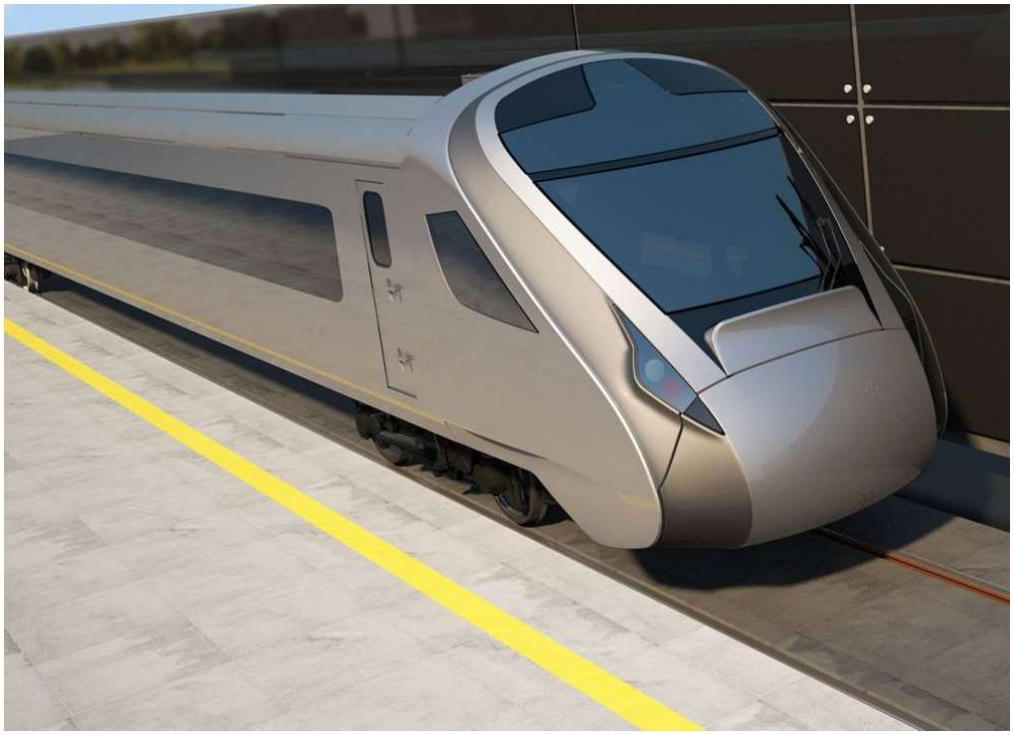
Bio-Vacuum System

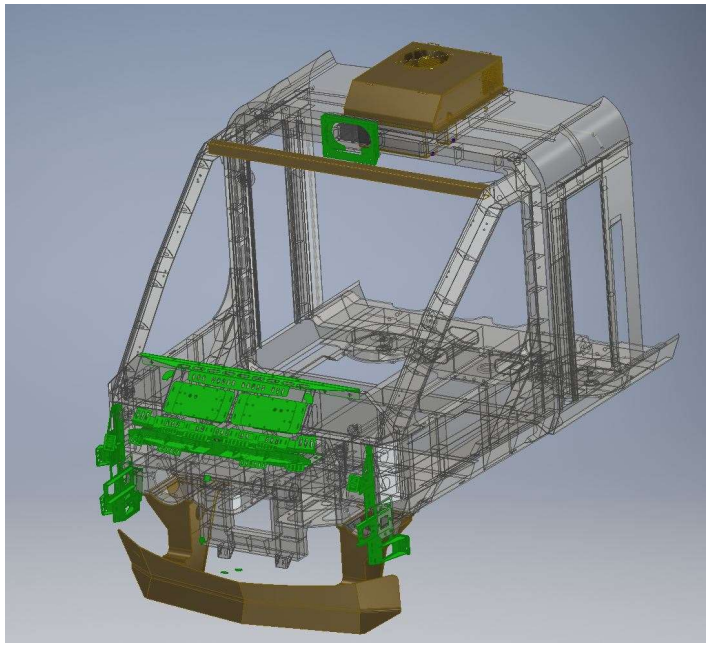
- ✓ Unique Design
- ✓ Zero Discharge and Clean Toilets



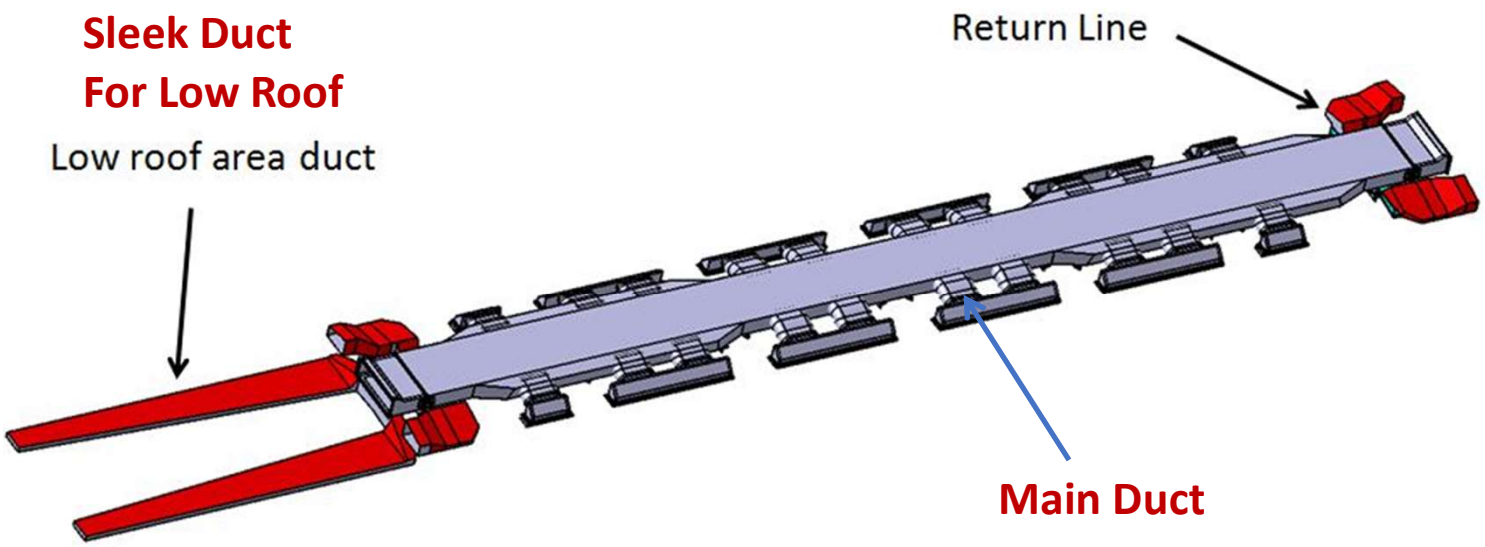


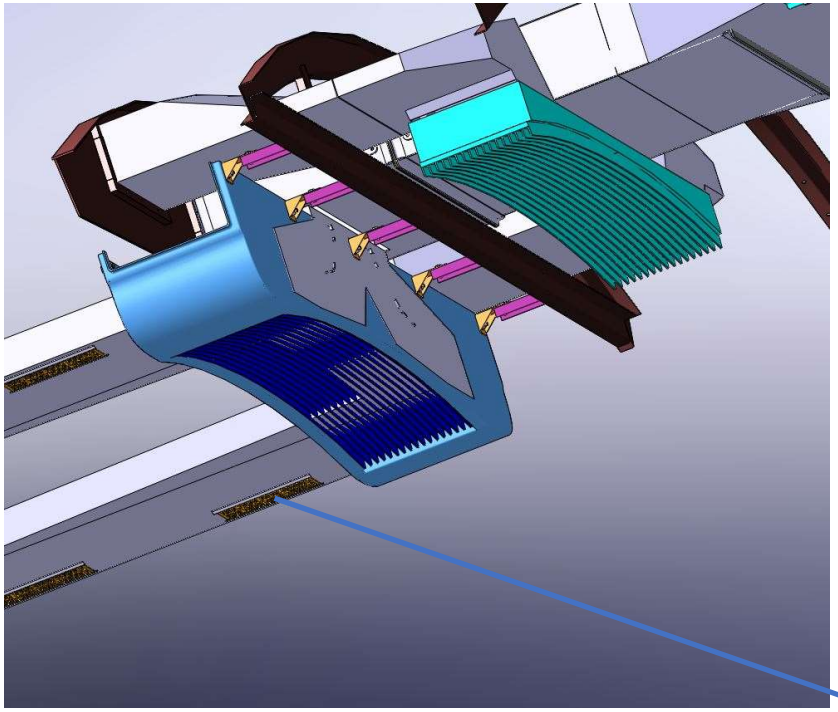
Continuous
Windows



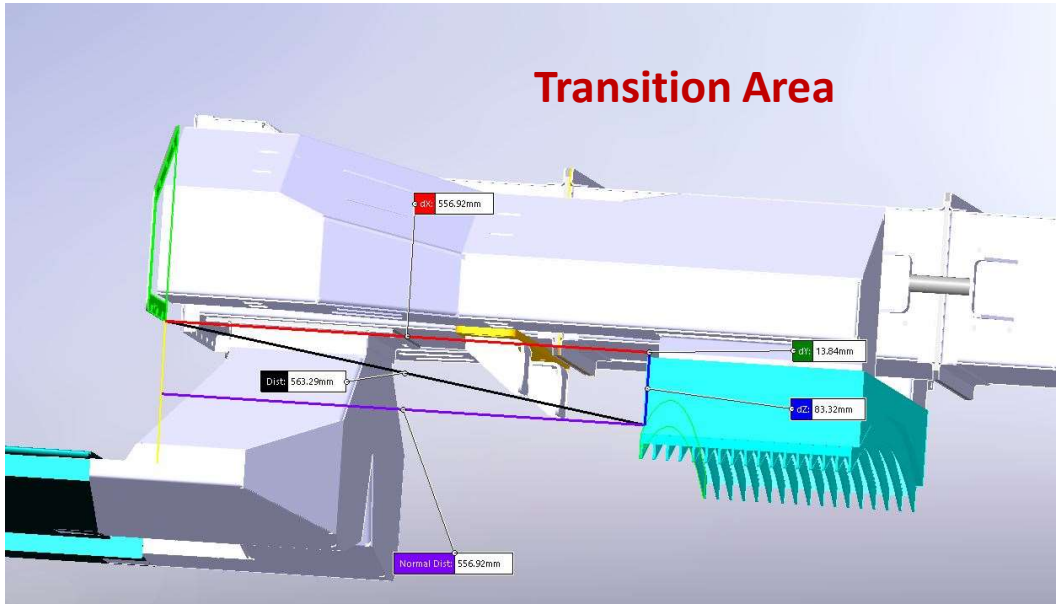


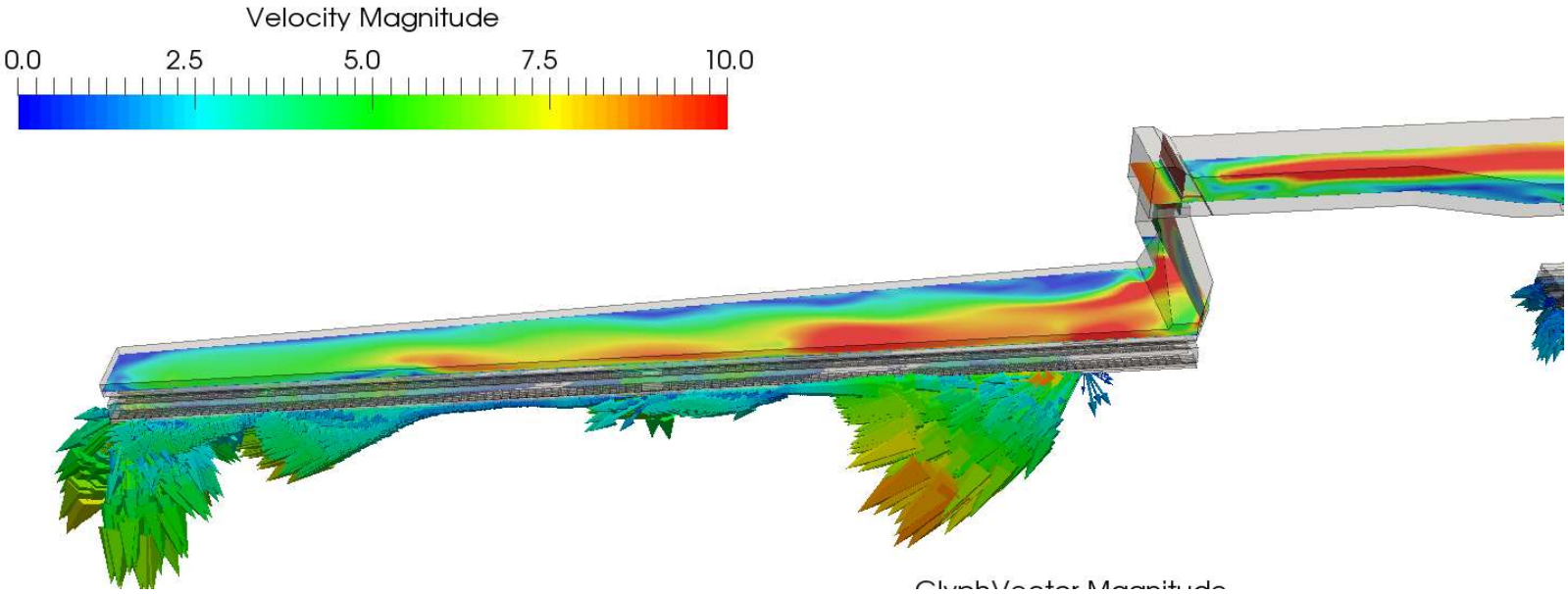
Sleek Duct
For Low Roof





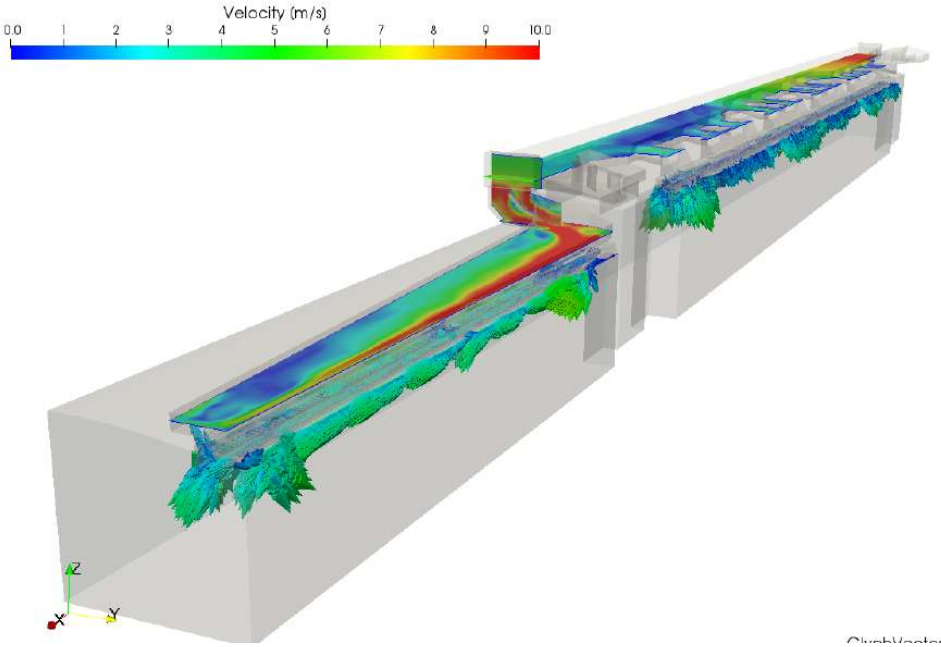
Low Roof Area





CFD Analysis

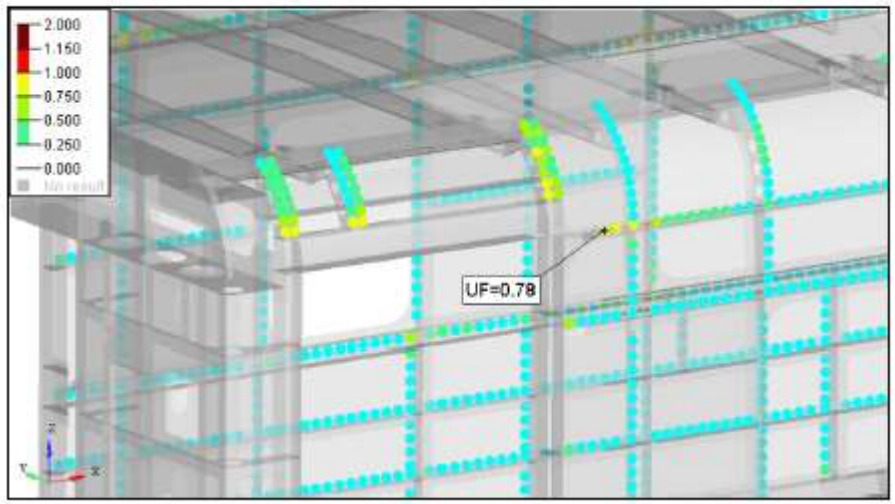
Final result Noise – Free Air-conditioning

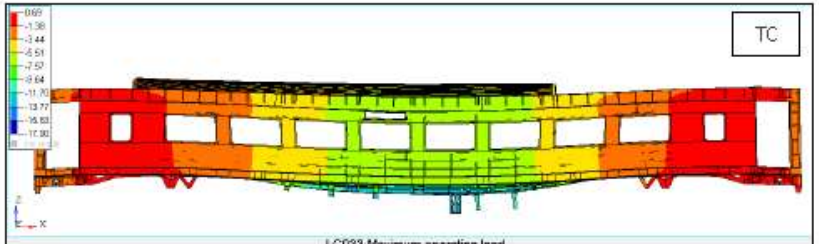


World Class Specifications and Validations

Car Body Design Validation

- Car body Design meets the requirements of EN 12663-1:2010+A1:2014 and DVS1612:2014.
  - EN 12663-1:2010+A1:2014. Railway applications. Structural requirements of railway vehicle bodies. Part 1: Locomotives and passenger rolling stock
  - DVS 1612:2014. Design and endurance strength assessment of welded joints with steels in rail vehicle construction





Bogies – Design Validation

- Dynamic Multi Body analysis shown stable behaviour upto 180 kmph according to EN 14363 and RDSO's Third Criteria Committee
- Simulation for the acceptance of running characteristics according to EN 14363:2016 - running behavior and stationary tests.
- The Simulation results matched the values of RDSO Trials

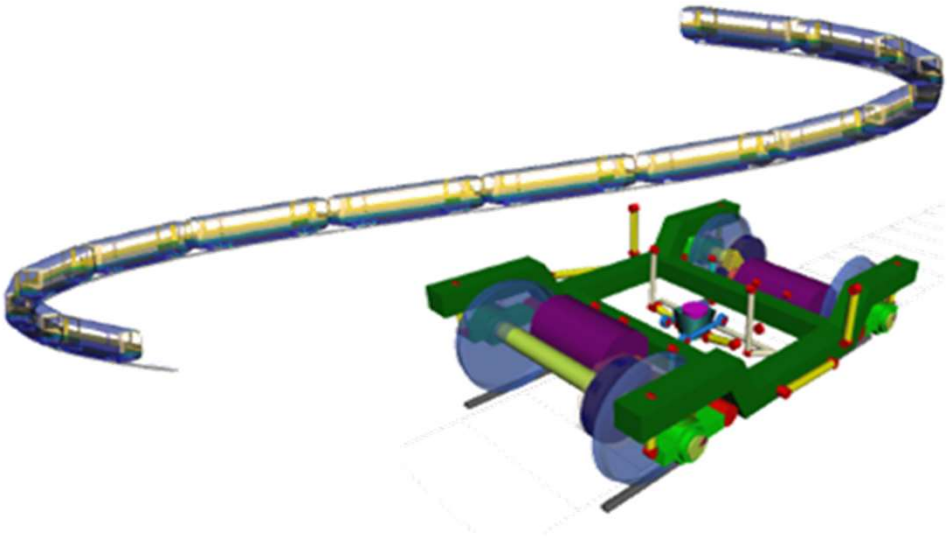
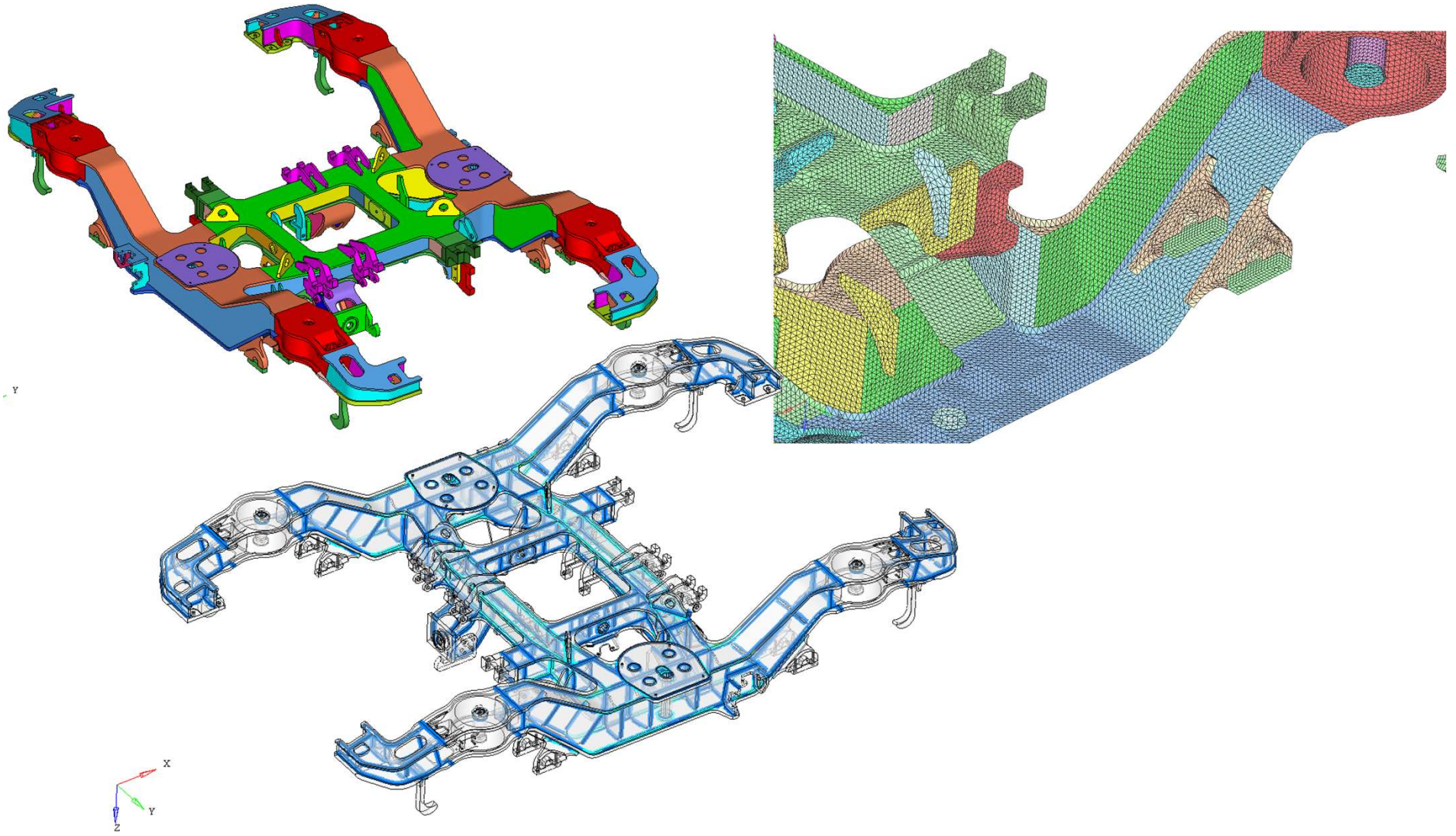
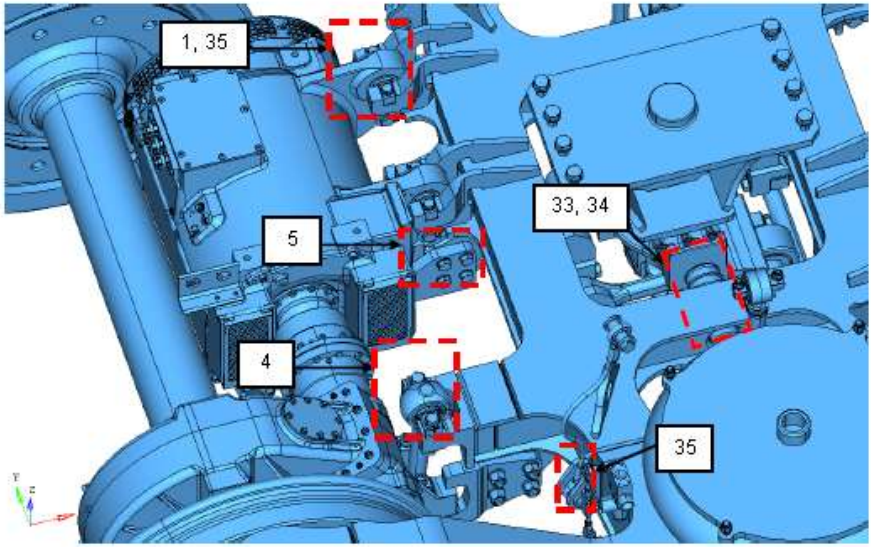


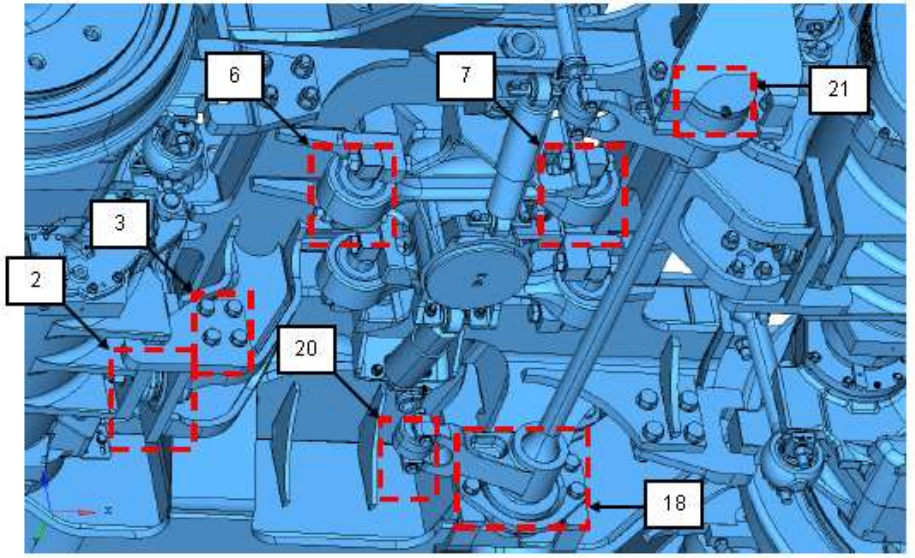
Fig. 31. Multibody model of vehicle.

Structural analysis of bogie frame according to EN 13749:2011

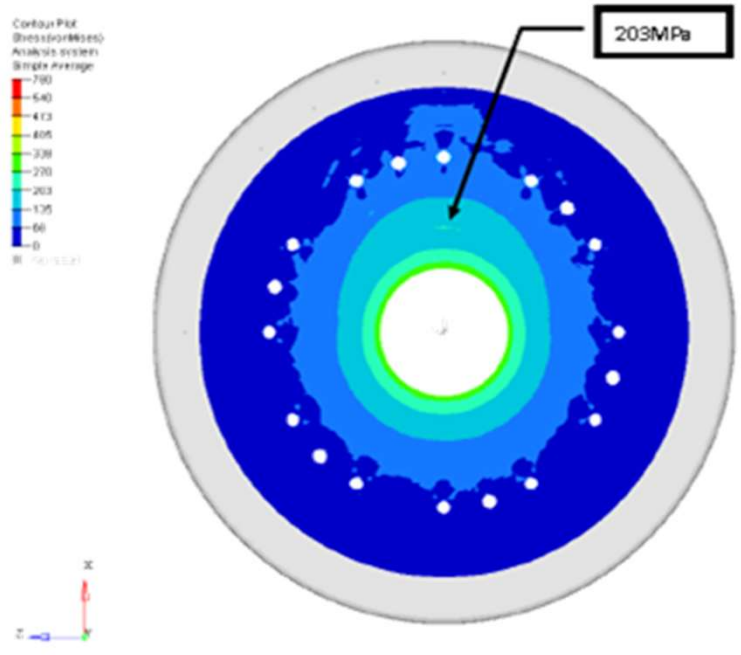


Structural analysis of bolted Joints - VDI2230:2014





Structural analysis of monoblock wheel according to EN 13979-1+A1 (2011)



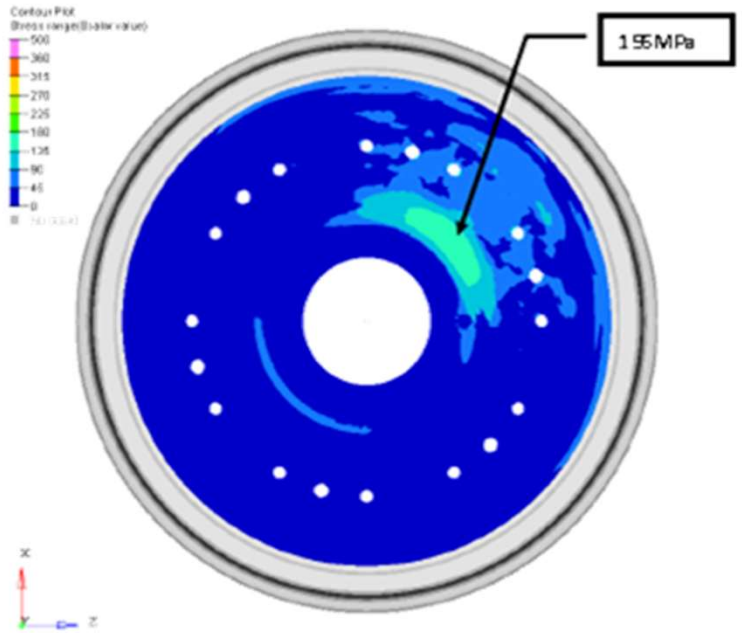


Fig. 9. Von Mises stresses for a new wheel, A-A section.

Project Management

Project management

- Real Trick – Selection of Good Vendors
- Made local vendors to source from the best in the world.
- Creative use of purchase powers – Single Tenders, SLT, Strict Specifications
- Special efforts in Seats, Flooring, Windows, FRP items, Couplers, Propulsion, Painting, Interior Panelling, Lights, Air-conditioning ducts, Brake System.

Project Management

Our vendors, most of them, lived up to the faith we reposed in them, often airlifting stuff from abroad to meet our deadlines.

Train-18 has seen an unprecedented cooperation of ICF designers, ICF production staff. Stores and Finance departments

and

Similar participations of designers and makers from vendors.

Project management

SHOP FLOOR MEETINGS WITH SUPPLIERS

The End