Technological and economic factors on the maximum design speed of high speed trains

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Overview

• Development of Speed in the Railway Sector

• Project Next Generation Train

• Increasing speed up to 600 km/h:
  • Operational aspects
  • Vehicle- and Aerodynamics
  • Signalling and Train Control

• Conclusion
Development of railway speed records

<table>
<thead>
<tr>
<th>Year</th>
<th>Speed [km/h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>100</td>
</tr>
<tr>
<td>1990</td>
<td>200</td>
</tr>
<tr>
<td>2000</td>
<td>300</td>
</tr>
<tr>
<td>2010</td>
<td>400</td>
</tr>
<tr>
<td>2020</td>
<td>500</td>
</tr>
</tbody>
</table>

- Experimental wheel-rail trains
- Commercial wheel-rail trains
- Experimental maglev trains
- Commercial maglev trains
- Hyperloop

Source: Wikimedia/Mrdeluna, Wikimedia/Alain Stoll, Wikimedia/Yosemite, Wikimedia/Marc Voß, Wikimedia/Clicsouris
Development of commercial speed

![Development of commercial speed chart](chart.png)

- **CRH400** - Source: Wikimedia/N509FZ
- **CRH3** - Source: Wikimedia/Brücke-Osteuropa
- **Shinkansen 0** - Source: Wikimedia/Nadate
- **TGV PSE** - Source: Wikimedia/Falk2
- **TGV Duplex** - Source: Wikimedia/PS-2507
Project Next Generation Train
Since 2007, 11 DLR Institutes, current phase until 2018

- Ultra-high-speed train (400 km/h, 202m, 800 seats, double-deck, 16 MW)
  NGT HST

- High-speed regional train (230 km/h, 120m, 480 seats, double deck)
  NGT LINK

- High-speed Cargo train (up to 400 km/h, currently in design process)
  NGT CARGO
Operational aspects of a commercial speed of 600 km/h
Passenger demand on reference line Paris-Vienna

- Usage of the NGT European Rail Passenger Model
- Gravity model with population and economy data
- Calibrated with 2010 Eurostat data

- 2,700 cities
- 2,000 train routes
- 20,100 km HSR
- 80,000 km Intercity
- 80,000 km regional
- 10.2m train-km/day
Operational aspects of a commercial speed of 600 km/h
Passenger demand on reference line Paris-Vienna

• Speed 300 ÷ 600 km/h: Increase of demand from 19 to 31 bn Pkm/year
• International traffic profits the most (especially Austria-Germany and France-Germany)

<table>
<thead>
<tr>
<th>Reference line Paris-Vienna</th>
<th>300 km/h</th>
<th>400 km/h</th>
<th>500 km/h</th>
<th>600 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time (hours)</td>
<td>4:42</td>
<td>3:51</td>
<td>3:23</td>
<td>3:03</td>
</tr>
<tr>
<td>Passengers (mio/year)</td>
<td>55.3</td>
<td>69.1</td>
<td>77.2</td>
<td>83.0</td>
</tr>
<tr>
<td>Passenger-km (bn. Pkm/year)</td>
<td>19.00</td>
<td>24.84</td>
<td>28.38</td>
<td>30.99</td>
</tr>
<tr>
<td>Energy consumption (at wheel) (MWh/run)</td>
<td>19.2</td>
<td>31.6</td>
<td>44.8</td>
<td>60.8</td>
</tr>
</tbody>
</table>
Operational aspects of a commercial speed of 600 km/h

Energy consumption

- Energy consumption increases by factor 3 from 300 to 600 km/h
- One run from Paris to Vienna: 20 † 60 MWh
- For very high speed: renunciation of traction force buffer † speed decrease in slopes † travel time increase hardly noticable
### Operational aspects of a commercial speed of 600 km/h

**Reference Timetable**

<table>
<thead>
<tr>
<th>Reference line Paris-Vienna</th>
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<th>400 km/h</th>
<th>500 km/h</th>
<th>600 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average speed (km/h)</td>
<td>244</td>
<td>297</td>
<td>338</td>
<td>375</td>
</tr>
<tr>
<td>Average speed of all passengers using the line at least for a part of the journey including dwell times (km/h)</td>
<td>119</td>
<td>130</td>
<td>138</td>
<td>146</td>
</tr>
<tr>
<td>Specific energy consumption at wheel level (Wh/(km * seat))</td>
<td>21.0</td>
<td>34.5</td>
<td>48.9</td>
<td>66.4</td>
</tr>
<tr>
<td>Number of NGT trainsets (incl. 10% operational buffer)</td>
<td>37</td>
<td>40</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Operational performance (Mio trainset-km/year)</td>
<td>29.4</td>
<td>36.3</td>
<td>40.7</td>
<td>46.3</td>
</tr>
<tr>
<td>Average operational performance of one NGT trainset (km/year)</td>
<td>786 000</td>
<td>916 000</td>
<td>973 000</td>
<td>1 052 000</td>
</tr>
<tr>
<td>Seat utilization (reservation compulsory)</td>
<td>81%</td>
<td>86%</td>
<td>87%</td>
<td>84%</td>
</tr>
</tbody>
</table>

### Diagrams

- **Reference line Paris-Vienna**
- **Operational performance (Mio trainset-km/year)**
- **Average operational performance of one NGT trainset (km/year)**
- **Seat utilization (reservation compulsory)**
Vehicle – Components to have a look at

**Car body**
- Dynamic Forces
- Aerodynamic Forces

**Interchange of cars**
- Pressure resistance
- Air flow (Noise, Resistance)

**Energy supply**
- Pantograph
- Noise

**Chassis**
- Track condition
- Wheel wear

**Brakes**
- Pneumatic
- Alternative Brake systems

**Doors & Windows**
- Pressure resistance

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**Propulsion**
- Installed Power
- Energy consumption
Infrastructure – Components to have a look at

**Energy supply**
- Substations

**Civil engineering**
- Tunnels, Bridges
- Air flow (noise, resistance)

**Line routing**
- Curve- & Rounding off radii
- Track spacing
- Line width

**Catenary**
- Contact wire cross section
- Contact wire tension

**Signalling**
- Train protection
- Train guidance

**Super structure**
- Ballast, Slab track
- Dynamic additional forces due to track geometry faults
Vehicle dynamics

- Sub-Tasks of the transportation task are: Load bearing, Guidance, Traction
- Guidance is depending on hunting motion, whose stability depends strongly on speed
- Measures: adjust stiffness of primary suspension, low equivalent conicity, additional yaw dampers, long wheel-base (everything solvable)
- Wear: Sliding friction, speed dependency is difficult to quantify
- Exemplary calculation with standard HSR configuration shows a progressive increase of abrasion due to guidance forces
- Traction potential drops with incr. speed, according to Curtius and Kniffler, friction coefficient $\mu = 0.1$
- Aerodynamical drag causes the equipment of as much wheels as possible to be powered
Aerodynamics

• Aerodynamic drag exceeds mechanical friction at higher speeds and increases with the square of driving speed
• Measures: long nose, plane surface, plane wagon interchange

• Also important: Crosswind stability especially with the lightweight construction (NGT as example)
• Measures: specific devices for active control of stability, wind (and noise) fences

• Noise problem: over 300 km/h aeroacoustic emissions dominate
• Pantograph sound scales with $U^6$ † measures for a noise-optimization such as the Shinkansen pantograph
Signalling and Train Control

• Braking distance grows approximately by square of the speed
• Current high-speed train control systems (e.g. ERTMS) could solve speeds up to 600 km/h without significant problems
  • Cab signalling instead of trackside signals
  • Radio connections capable of working with high-speeds
  • Balise message transmission capable of working with high-speeds
• Due to long braking distances the Moving Block promises higher capacity (fixed obstacles like junction switches can be found in areas with lower speed)
Conclusions

- Many technical aspects can be solved (like speed records show)
- The problem will be the economic side: effort grows progressive, the benefit (travel time reduction) decreases, energy consumption is only a small part