FIRE PERFORMANCE OF PASSENGER TRAINS

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INTRODUCTION

• Understanding train fire behavior and estimation of credible design fires is critical to fire safety design of rail infrastructure.

• This talk gives an update to my 2010 Master’s thesis titled “Fire development in passenger trains”.
## FIRE SCENARIOS

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>Location</th>
<th>AS 4825 Fire scenario category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small train fire</td>
<td>Small fire &lt; 50 kW which does not spread beyond the location of fire origin</td>
<td>Train - Internal or external</td>
<td>“Design fire scenario”</td>
</tr>
<tr>
<td>Medium train fire</td>
<td>Arson fire involving seat and wall/ceiling linings or large equipment fires which does not spread beyond the area of fire origin</td>
<td>Train - Internal or external</td>
<td>“Design fire scenario”</td>
</tr>
<tr>
<td>Fully developed train carriage fire</td>
<td>Arson fire resulting in flashover and fully developed carriage fire</td>
<td>Train - Internal</td>
<td>“High challenge design fire scenario”</td>
</tr>
<tr>
<td>Multi-car train fire</td>
<td>Arson fire resulting in flashover and fire spread to multiple train carriages</td>
<td>Train - Internal</td>
<td>“Extreme Event”</td>
</tr>
</tbody>
</table>
**STANDARDS**

**AS 4825:2011 – TUNNEL FIRE SAFETY**

Identify / categorise scenarios as:

1. Design fire scenarios
2. High challenge design fire scenarios
3. Extreme events

<table>
<thead>
<tr>
<th>HRR (MW)</th>
<th>Rail vehicles</th>
<th>Metro vehicles</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Electric locomotive</td>
<td>Low combustible passengers carriage</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>Normal combustible passengers carriage</td>
</tr>
<tr>
<td>30</td>
<td>Passengers Carriage</td>
<td>Two carriages</td>
</tr>
<tr>
<td>50</td>
<td>Open Freight wagons with trucks</td>
<td>Multiple carriages (more than 2)</td>
</tr>
</tbody>
</table>
STANDARDS
ROLLINGSTOCK FIRE SAFETY

NFPA 130
BS 6853 (superseded)
DIN 5510-2 (withdrawn)
NF F 16-10

EN 45545:2013 (part 2 fire performance of materials)

AS 7529.3 (2014)
Upper wall and ceiling linings critical.

Critical ignition source peak HRR for fire growth beyond the ignition area = 100-300 kW.
FIRE EXPERIMENTS
CSIRO – FULL SCALE
FIRE EXPERIMENTS
EUREKA PROJECT

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Fuel load (MJ)</th>
<th>Ignition source (kg isopropanol)</th>
<th>Result</th>
<th>HRR $\pm 25%$ (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subway car steel Body (F31)</td>
<td>32,670</td>
<td>0.7</td>
<td>Carriage burnt out Fire duration 20 min</td>
<td>-</td>
</tr>
<tr>
<td>Rail car steel body</td>
<td>62,480</td>
<td>6.2</td>
<td>Carriage burnt out Fire duration 70 min</td>
<td>20</td>
</tr>
<tr>
<td>Rail Car steel body</td>
<td>76,890</td>
<td>6.2</td>
<td>Carriage burnt out Fire duration 100 min</td>
<td>14</td>
</tr>
<tr>
<td>Subway car Aluminium body</td>
<td>41,360</td>
<td>6.2</td>
<td>Carriage burnt out and roof melted away Fire duration 20 min</td>
<td>35</td>
</tr>
</tbody>
</table>

FIRE EXPERIMENTS
KORREA RAILROAD RESEARCH INSTITUTE / CARLTON UNIVERSITY

Test 1- Intercity Coach

Test 1- Subway Car

Images courtesy of papers by Lee, Hadjisophocleous et al 2013 and 2016
Metro test 2 interior (left) and test 3 interior (right)

Metro Test 2 (left) and Test 3 (right)

Images courtesy of Metro Project report 2012
FIRE EXPERIMENTS
METRO PROJECT

Metro test 2 and 3 HRR

Metro test 2 and 3 HRR time shifted & compared against $t^2$ growth rates

Images courtesy of Metro Project report 2012

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FIRE EXPERIMENTS
OTHER LARGE SCALE MOCK UP TESTS

• NFPA 130 compliant interior (Coles et al & Zicherman) - No flashover for 200kW ignition source. Flashover for 500 kW ignition source

• EN 45545-2 compliant interior (Guillame et al & Capote et al) – No flashover for ignition sources up to 150 kW

Images courtesy of paper by Zicherman 2015
DESIGN FIRES USED IN THE PAST

PEAK HRR

Survey of design fires by Agnew and Stacey (left)

CSIRO surveys indicate broad range of assumed design fires, 5-41 MW

DESIGN FIRE ESTIMATION METHODS

- t-squared growth rate
  \[ \dot{Q} = \alpha t^2 \]

- Average HRR Method
  \[ \dot{Q}_{ave} (MW) = \frac{\text{Total Fuel Load (MJ)}}{\text{Burn Duration (s)}} \]

- Duggan’s Method
  \[ \dot{Q}(t) = \sum \left( \frac{A_i \dot{q}_i(t)}{1000} \right) \]

- Ventilation Controlled Burning
  \[ \dot{Q}_{\text{Ventilation Controlled}} = \eta 1500 A_0 \sqrt{H_0} \]
DESIGN FIRE ESTIMATION METHODS
CFD PYROLYSIS MODELS

• FDS modeling of fire spread to predict full scale HRR curves for rail vehicles cannot currently be relied upon without large or full scale tests on the specific vehicle materials for validation.

• Determination of material property inputs for the pyrolysis model is difficult. Often inputs determined from bench scale tests need adjusting to achieve reasonable results when matched against large or full scale validation fire tests.

• The pyrolysis models may not suitably address materials which are complex combinations of different material layers.

• FDS may have some limitations when modelling post flashover, ventilation controlled, non-stoichiometric combustion

• User competence – Tempting to rely on model inputs without full consideration of limitations – “rubbish in = rubbish out”.
DISCUSSION ON TRAIN FIRE BEHAVIOUR

- A single $t^2$ growth rate for the entire rail vehicle HRR, including pre and post flashover phases is an oversimplification.
- Pre-flashover phase, fire is localised and typically can grow at initial rate any ware between Medium $t^2$ to Ultrafast $t^2$.
- Onset of flashover is a tipping point / transition from localised fire to rapid spread to entire interior. Flashover is not a discrete event such as ignition, but rather it is a rapid fire growth which occurs over a short period of time.
- From onset of flashover, there is a second, faster stage of growth which is typically faster than an Ultrafast $t^2$.
- If there are no restrictions on ventilation the fire continues to grow at this rate until the fire becomes fuel controlled.
- However if there are restrictions on ventilation (limited number of doors open), post flashover fire growth is halted/throttled at HRR which ventilation openings are capable of supporting and then the fire growth will be slower and controlled by the rate of progressive failure/opening of items such as initially closed windows and doors.
MODIFIED DESIGN FIRE ESTIMATION METHOD PROPOSED BY CSIRO

Duggan's method HRR
Modified method HRR
- Ultrafast $t^2$ growth up to 500 kW
- Duggan's HRR shifted to onset of flashover
- Ventilation controlled HRR Plateau up to assumed time of window failure
- Maintained at steady peak HRR until 50% of fuel load is consumed
- Linear decay rate calculated based on 90% of fuel load consumed.

- Medium $t^2$ growth up to 500 kW

Heat Release Rate (MW)
Time (s)

0 200 400 600 800 1000 1200 1400 1600 1800
0 200 400 600 800 1000 1200 1400 1600 1800

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CONCLUSIONS

- This presentation gives an update on changes since my 2010 thesis.
- New rail safety standards and full scale train fire experiments have been reviewed.
- A modified design fire estimation method is proposed.
- Due to simplifying assumptions this method is unlikely to be completely valid/accurate but it is considered to more realistically describe train fire behavior than the existing simplified methods.
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