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Consequences of catastrophic hydrogen jet releases

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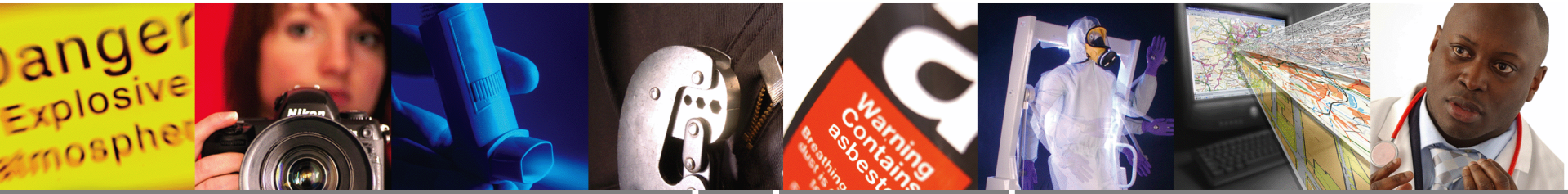

Introduction

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- Aim of experiments was to provide data for informing safety distances for hydrogen storage
- Work primarily focused on compressed hydrogen storage for stationary fuel cell systems – Hyper project
- All releases were made from storage at 200 bar
- Series of experiments undertaken to compare ignition position and timing
- Different sized orifices were used to simulate leaks

Facility

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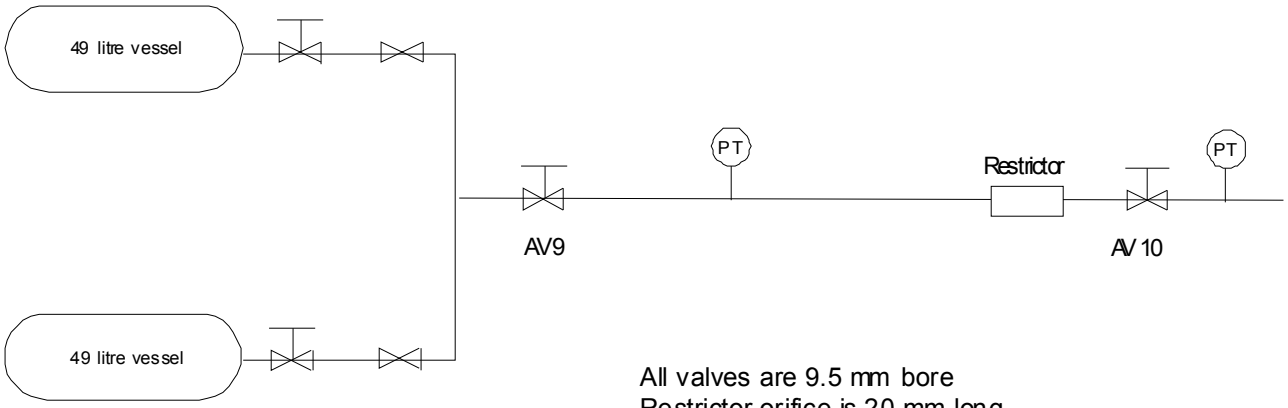
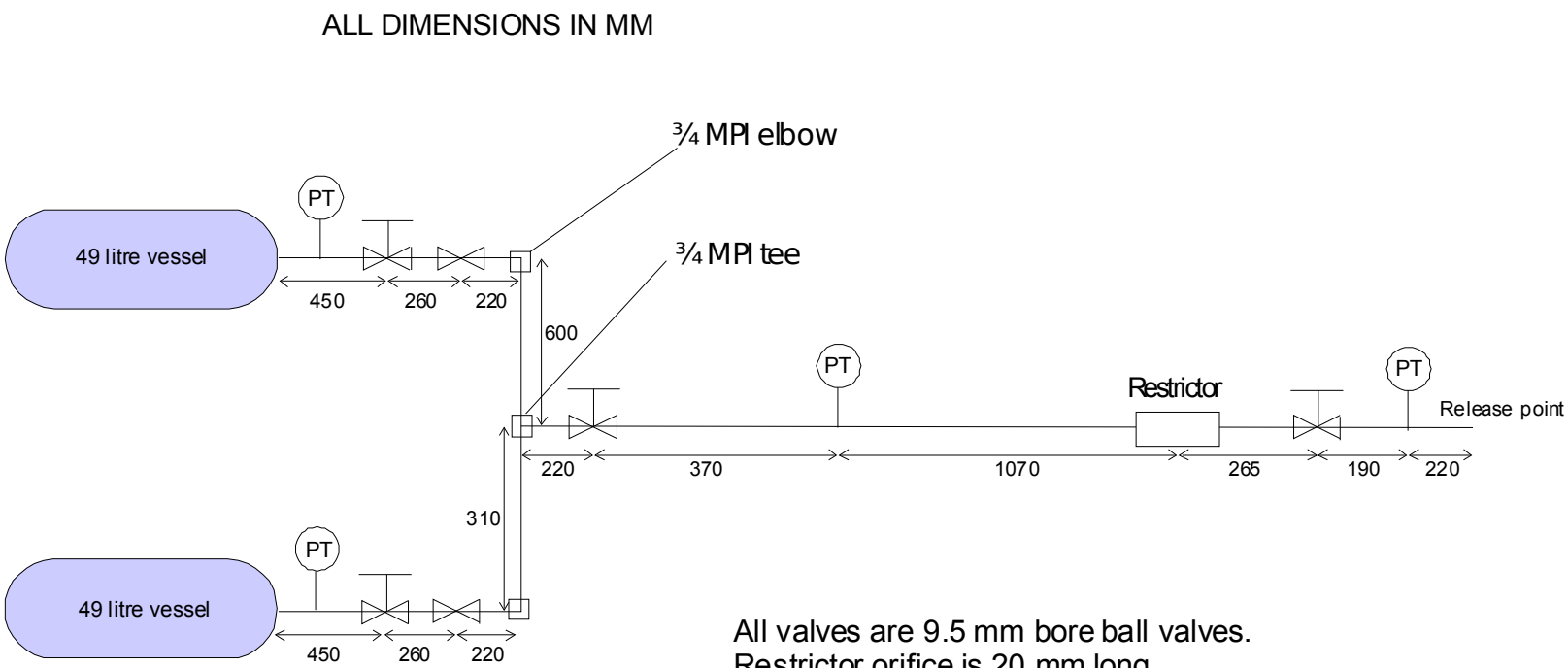
Simplified schematic of release system



All valves are 9.5 mm bore
Restrictor orifice is 20 mm long
Tubing internal diameter is 11.9 mm

Detailed schematic of release system



All valves are 9.5 mm bore ball valves.
Restrictor orifice is 20 mm long.
Tubing internal diameter is 11.9 mm.
All elbows and tees are full pipe ID internally.
Both vessels are used for the releases.

Final release valve opening time is approximately 260 ms

Test variations

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- Used 1.5, 3.2, 6.4 and 9.5mm orifices in pipe-work (peak flow rates of 30, 120, 300 and 490g/s).
- Single ignition position 2 m from release point – varying ignition timing.
- Single ignition timing 800ms – varying ignition position
- Jets released along the ground to determine effect of attachment

Measurements

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For all tests

- **Pressure in the vessels**
- **Release pressure**
- **Overpressure on initial ignition of the jet**
- **Additional measurements made for selected tests using thermal imaging equipment and BOS**

Work Plan

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- Perform hydrogen jet releases at 200 bar into free air.
- 40 tests performed with different orifices, different ignition delays and different ignition positions
- tests done with both electrical and pyrotechnic ignition systems
- Schlieren video taken on selected tests.

Ignition source

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- Initial tests performed using electrical ignition system.
- Schlieren showed significant disturbance in the flow field due to the bulk of the device.
- Switched to pyrotechnic ignition system for subsequent tests

- Pyrotechnic ignition can ignite hydrogen cloud at more than one point

Flow disturbance

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Background oriented Schlieren

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- Background set up 3m behind jet
- Background measured 6m long by 2.4 m high
- Jet height was 1.2m
- Bottom of background was at ground level

BOS setup

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1.5mm orifice Schlieren- 800ms ignition delay

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3.2mm orifice Schlieren - 800ms ignition delay

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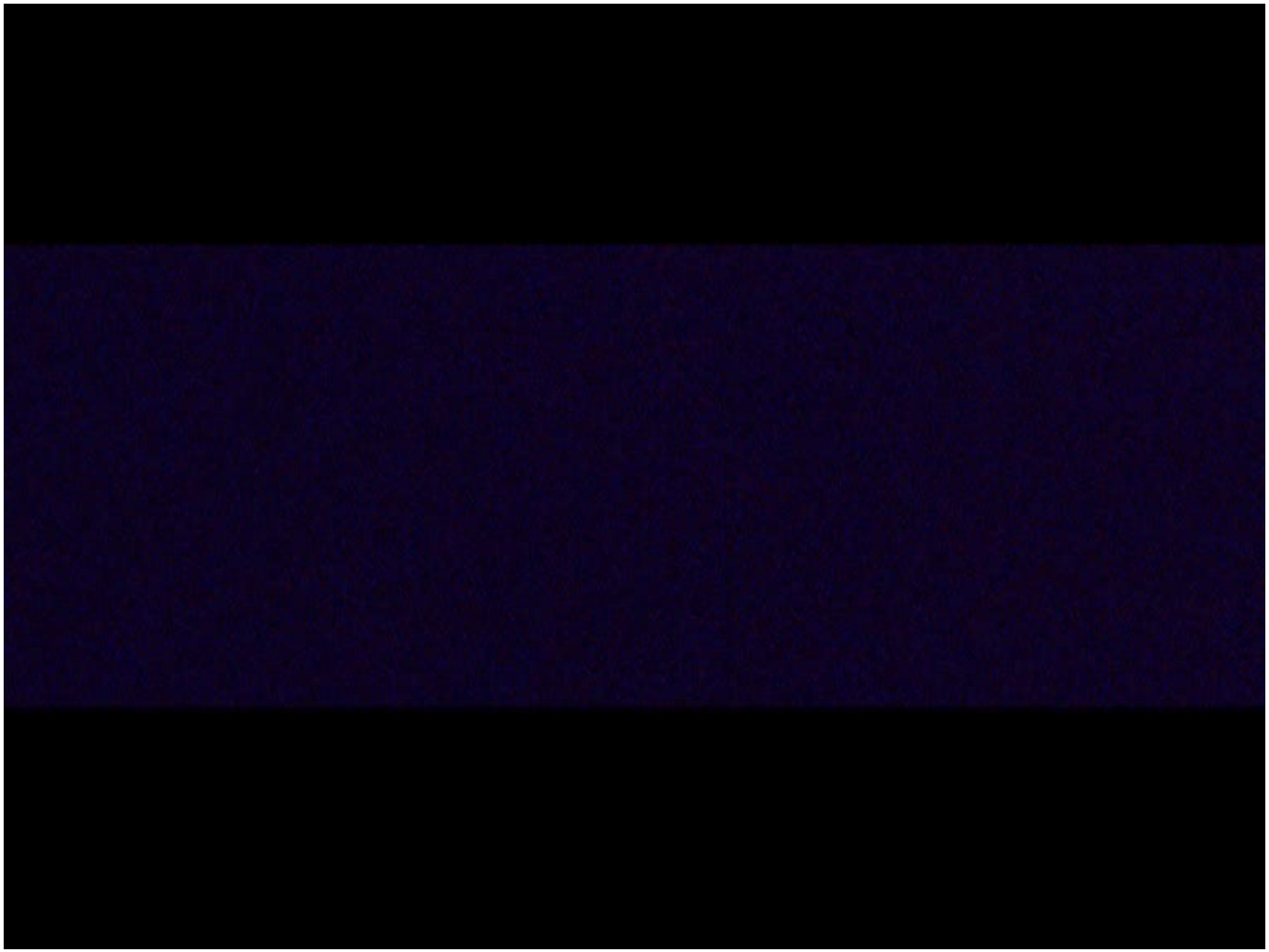

9.5mm orifice Schlieren - 800ms ignition delay

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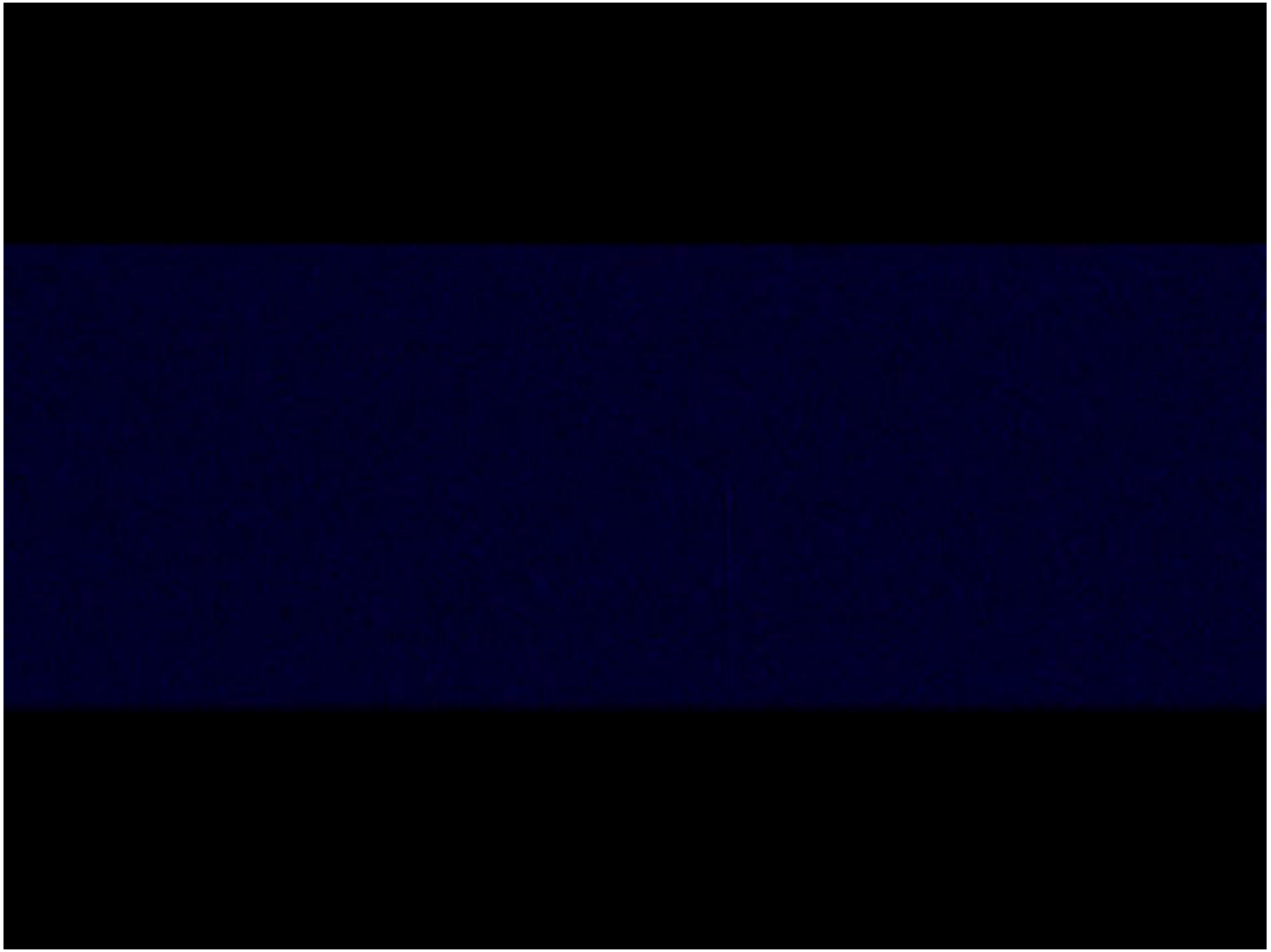

Shock waves

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Infra-red and spectrophotometry

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- Infra-red video taken at 4 different wavelengths at 100 frames per second
- Video shown is in waveband 4.1 – 5.3 micrometers

Infra-red
9.5mm orifice - 410ms delay

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Results – maximum overpressures

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Ignition delay of 800 ms

Orifice diameter (mm)	Ignition delay (ms)	Max overpressure (bar)
1.5	800	NR
3.2	800	0.035
6.4	800	0.152
9.5	800	0.165

Effect of varying ignition delay

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TEST PARAMETERS

- Single orifice release - 6.4mm
- Fixed pressure (205 bar)
- Fixed ignition position
- Ignition delay varied from 400ms to 2000ms
- Overpressures measured

Results – Max overpressures

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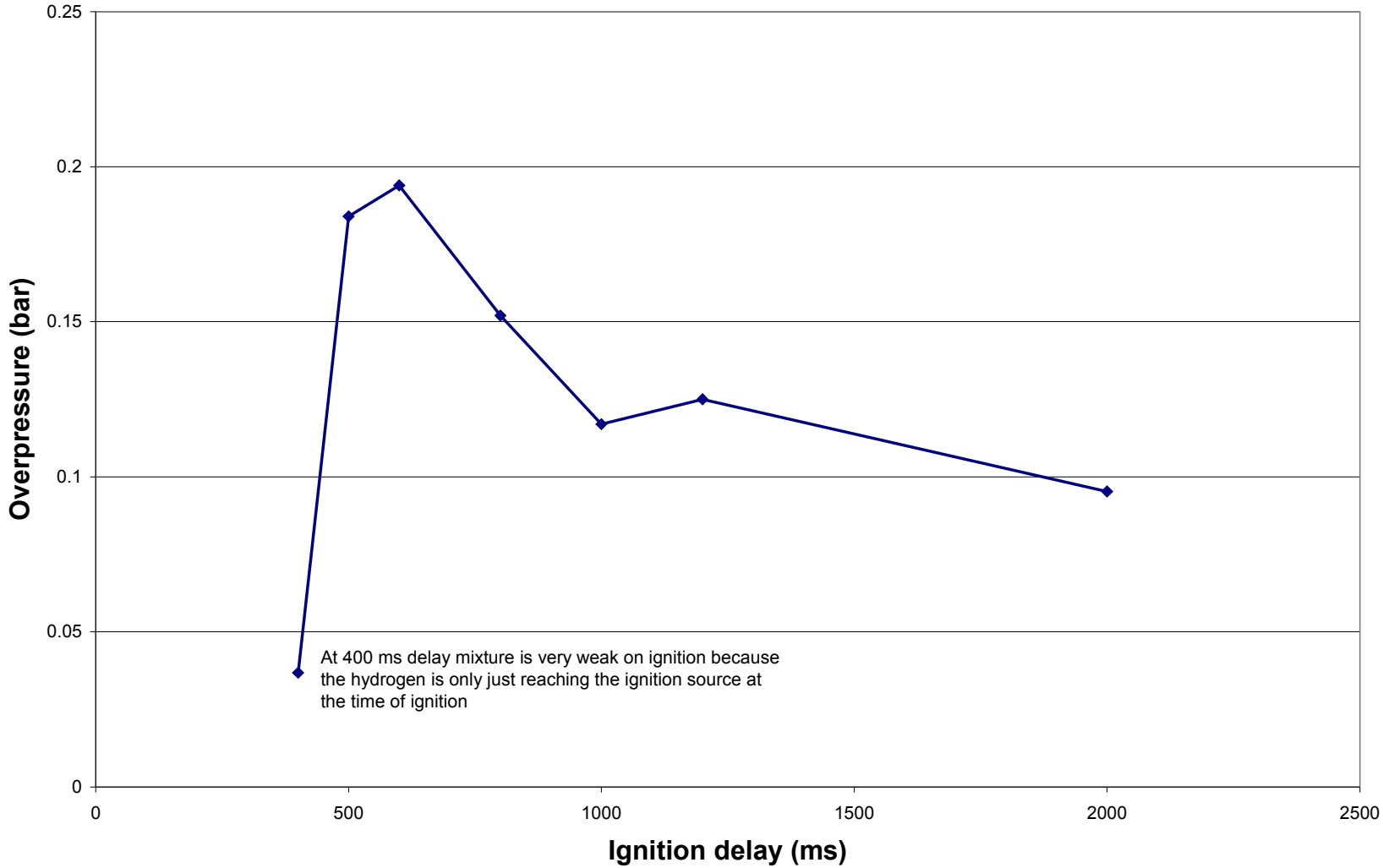
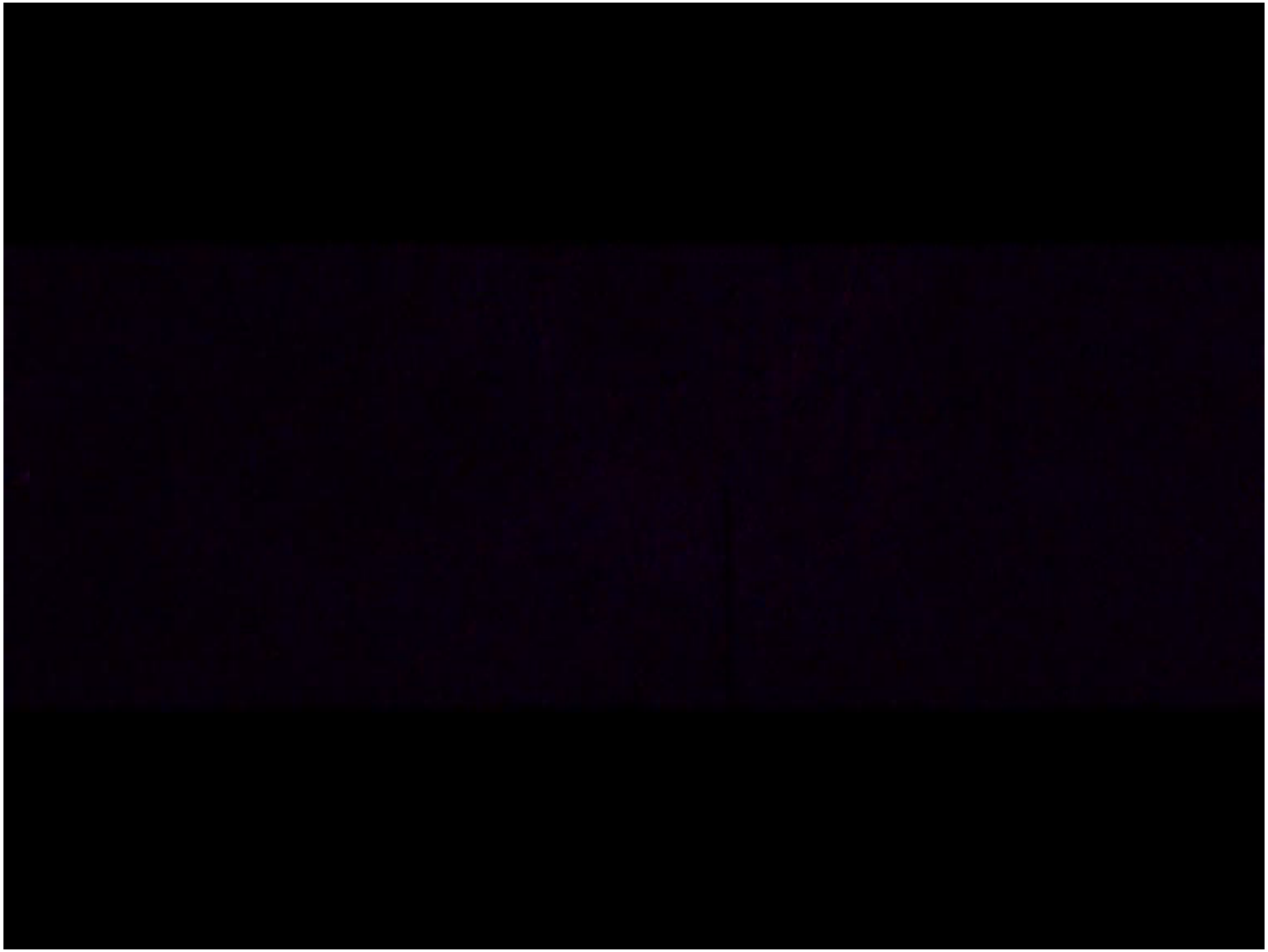
Effect of varying ignition delay

Release pressure (bar)	Orifice diameter (mm)	Ignition delay (ms)	Max overpressure (bar)
205	6.4	400	0.037
205	6.4	500	0.184
205	6.4	600	0.194
205	6.4	800	0.152
205	6.4	1000	0.117
205	6.4	1200	0.125
205	6.4	2000	0.095

Plot of overpressure against ignition delay



400ms ignition delay (h21)



At 400ms delay hydrogen mixture is very weak and only just reaching the ignition source at time of ignition

Effect of varying ignition position

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TEST PARAMETERS

- Single orifice (6.4mm) chosen
- Fixed pressure (205 bar)
- Fixed ignition delay (800ms)
- Ignition position varied from 2m to 10m
- Overpressures measured

Results – Max overpressures

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Effect on overpressures of varying ignition position

Release pressure (bar)	Orifice diameter (mm)	Ignition position (m)	Max overpressure (bar)
205	6.4	2	0.152
205	6.4	3	0.050
205	6.4	4	0.021
205	6.4	5	0.021
205	6.4	6	NR
205	6.4	8	NR
205	6.4	10	No ignition

Attachment effects

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TEST PARAMETERS

- **All orifices used**
- **Fixed pressure (205 bar)**
- **Fixed ignition delay (800ms)**
- **Fixed Ignition position**
- **Attached jets released along ground at height of 110 mm**
- **Unattached jets released at a height of 1.2 m**
- **Flame lengths measured**

Results – Flame length

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Flame lengths attached and unattached jets

Release pressure (bar)	Orifice diameter (mm)	Ignition delay (ms)	Attached Flame length (m)	Unattached Flame length (m)
205	1.5	800	5.5	3.0
205	3.2	800	9.0	6.0
205	6.4	800	11	9.0
205	9.5	800	13	11.0

Attached jet

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Unattached jet

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Discussion

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- Larger orifice – more hydrogen – larger overpressure
- 400ms ignition delay gives much lower overpressures than 800ms delay – probably due to the lean mixture at ignition time.
- Overpressure goes through a maximum at around 600ms and rapidly falls off with increasing delay
- Overpressure reduces with increasing ignition distance – no recordable pressure at 6 & 8 m and no ignition at 10 m
- It is probable that overpressures developed are dependent on the mixture, extent of mixing and degree of turbulence at ignition time.
- Initial findings for attached jets are that attachment effects are most evident for smaller orifices – possibly due to the increased turbulence associated with larger releases.

Conclusions

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- The inclusion of flow restrictors in hydrogen supply line reduces the flame lengths observed, therefore reducing safety distances required.

- From the experiments carried out it is apparent that jets from hydrogen storage at 200 bar are predominantly momentum driven, i.e. the cloud is relatively non-buoyant within the flammable range.

- When a release is orientated such that attachment to a surface can occur the jet length may be enhanced.

Conclusions

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- Ignition in a weak region of the jet cloud results in a relatively slow burn and hence a small overpressure.

- Maximum overpressures were observed when the ignition timing coincided with the area of maximum turbulence within the front portion of the jet reaching the ignition point.