Propellant Disappearing Gun Concept Trials

Phase 2

Mark Brinsden
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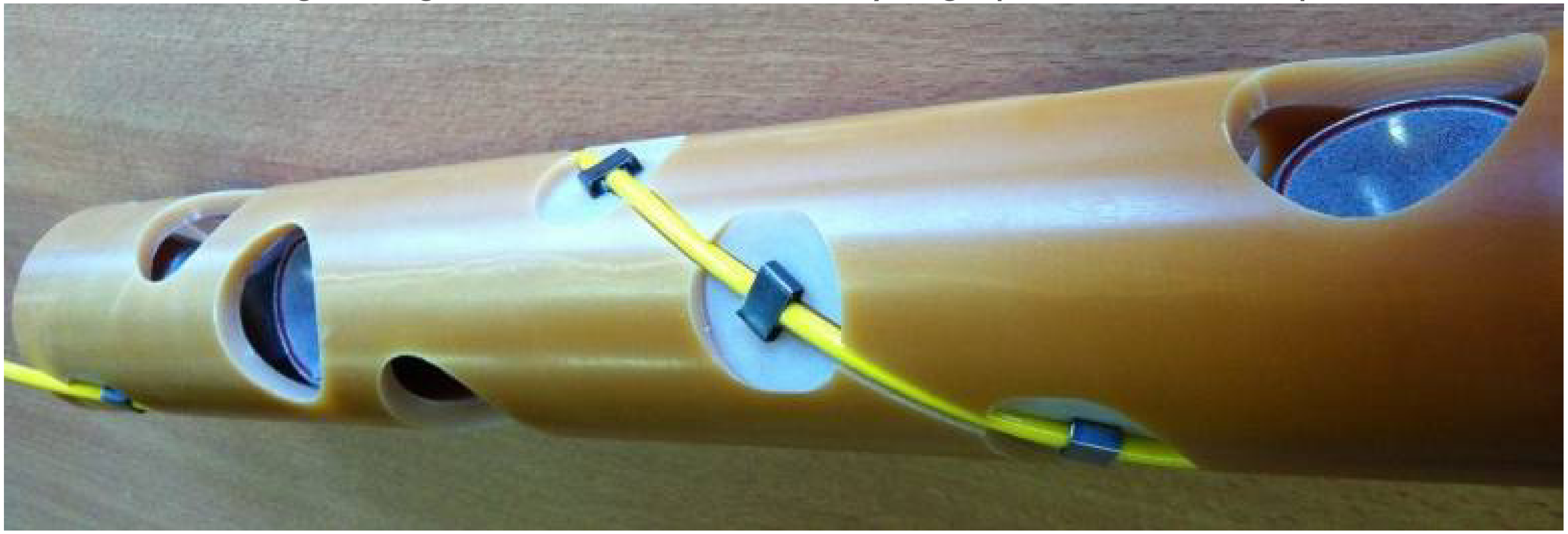
Purpose of the GameChanger

- Develop a gun that could be run on completion and disappear
- This can lead to a fast well turnaround and reduce post-perf shoot & pull reservoir damage in horizontal wells
- The gun would replace some existing technology (i.e. can be widely applied)
- Potential high value: For example 500 perf jobs with 2 days rig savings per job would lead to approx. $ 1 B savings. (example subsea wells over a 10 year period)
- Potential increase in well productivity, due to post perf damage mitigation and improved perforator performance.
- Leads into a full family of new propellant and non propellant disappearing gun systems, including guns suitable for more effective remedial perforation and stimulation of existing depleted well stock.

Envisaged Solution

- A carbon fiber reinforced polymer (CFRP) housing
- Optimally distributed propellant system
- Key Challenges/Risks
  - CFRP debris housing should be sufficiently small (< 10mm x 10mm) to flow back
  - CFRP strong enough to withstand moderately high pressure and temperature



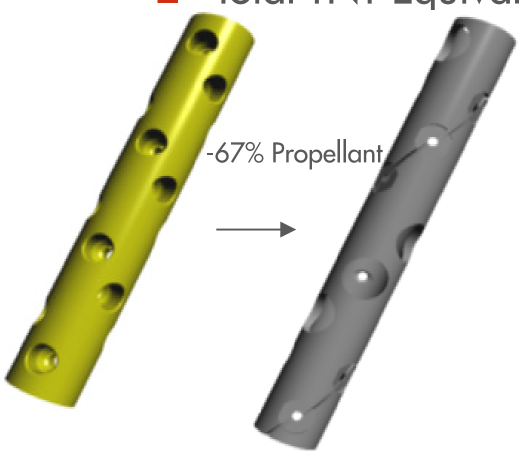
Recap Phase 1

$ 350k

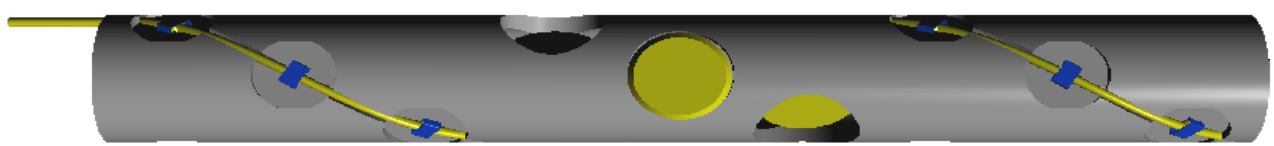
- In phase 1 a possible design concept has been tested, but:
  - Housing strength not good enough
  - CFRP debris dimensions Larger than 5mm x 5 mm
- Phase 2 plan:
  - Improved housing
  - Optimized shaped charge configuration and propellant loading tube
  - Optimized propellant load
  - Full scale test
  - Carry out small scale tests to cost effectively review / rule out various alternatives

Changes in concept in phase 2

- 6.7 mm thick CFRP housing self supporting and made from tougher (less brittle) carbon fibre
- Potassium Perchlorate Epoxy hollow propellant core developed:
  xx% oxidizer / yy% epoxy – advanced vacuum and ultrasonic molding technology
- 9 x Zinc 32g HMX DP2 shaped charges with external helical detcord integrated into propellant core (60~ phasing, 16.5 shots per meter 5spf) Shot density could be increased.
- Total TNT Equivalent ~1.5 kg

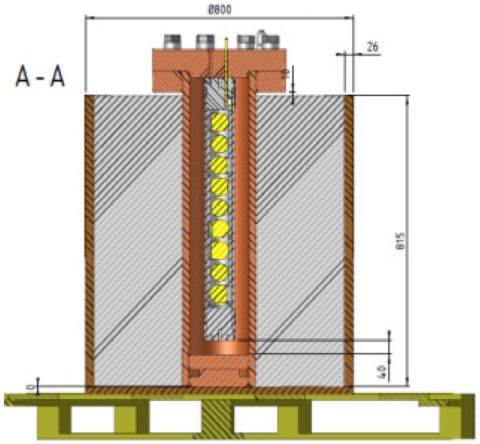


phase I phase II



Results Phase 2: Full scale Test

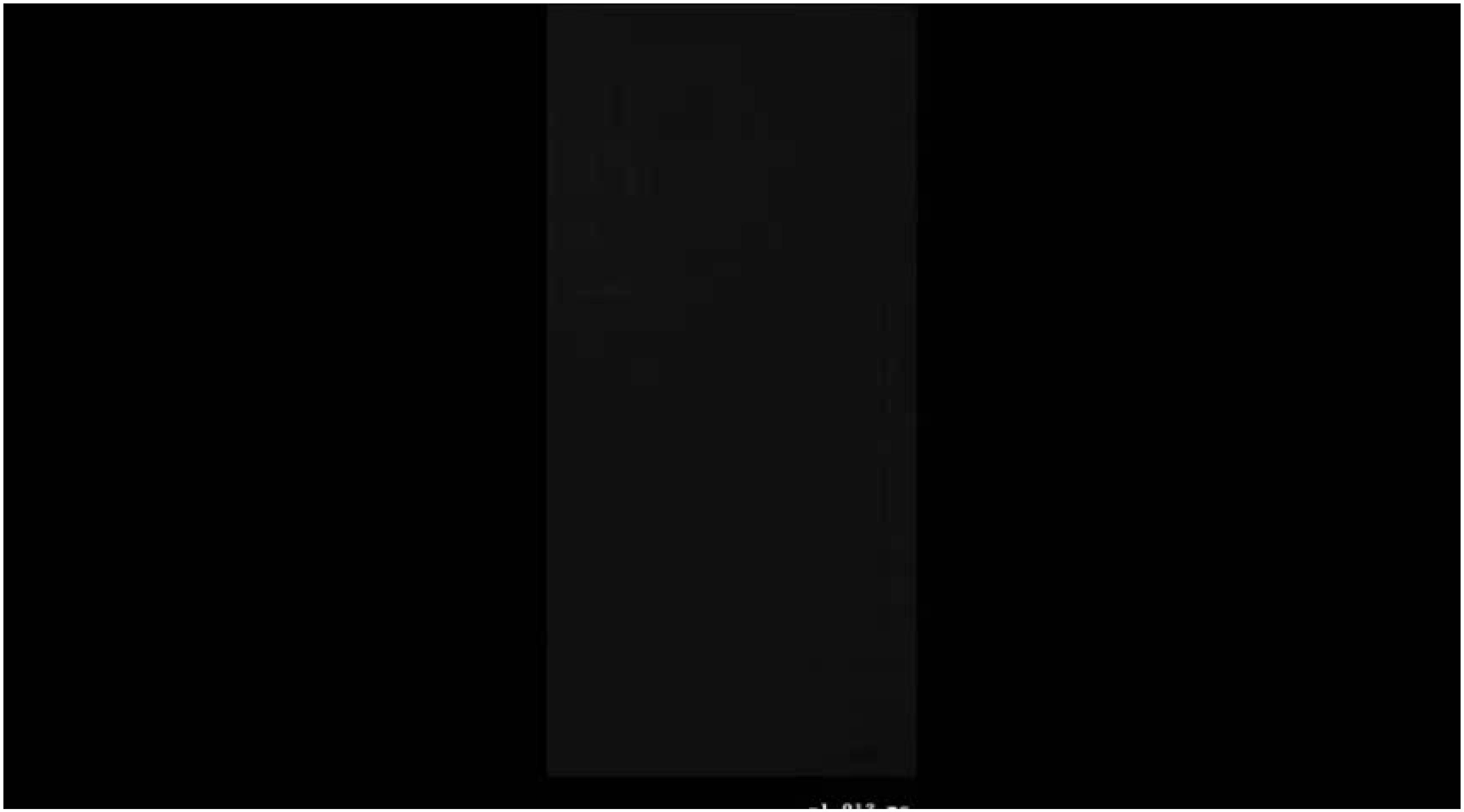
- Closed vessel test
  - **<u>Assembly</u> <u>loaded</u>** and **<u>fired</u>** inside 20 mm thick steel closed vessel under 400 bar pressure
    - Bottom, walls and lid fail at ~ 2000 bar
    - Rupture disc in lid fails at ~ 750 bar
  - Closed vessel is retained by 400 mm concrete and 26 mm steel container
  - (no steel container used under phase I)



Results Phase 2: Full scale Test - ASSEMBLED

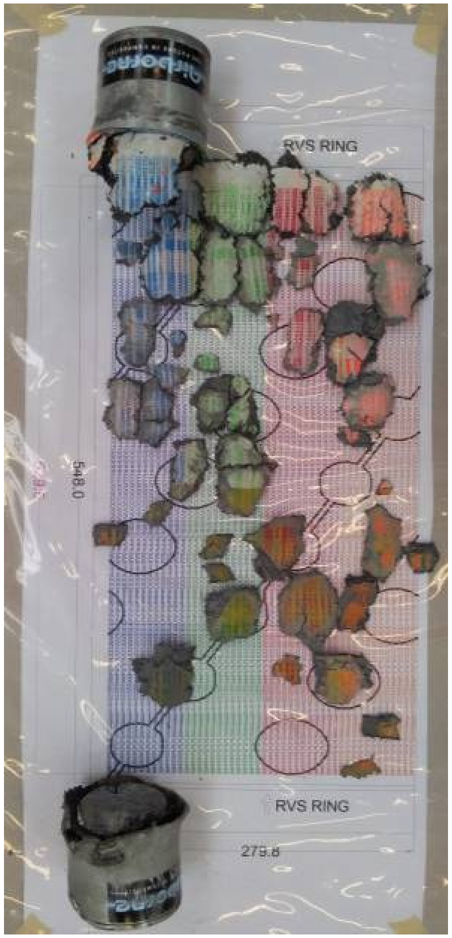
Results Phase 2: Full scale Test - LOADED

Results Phase 2: Full scale Test - FIRED



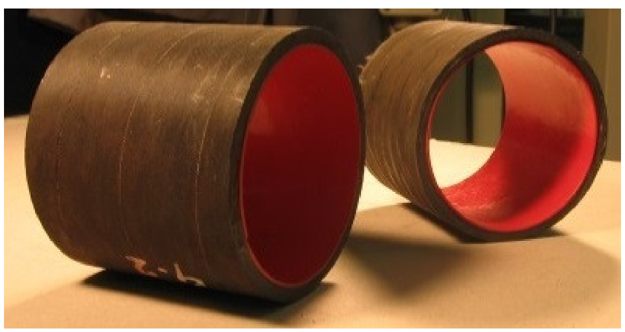
Results Phase 2: Full scale Test

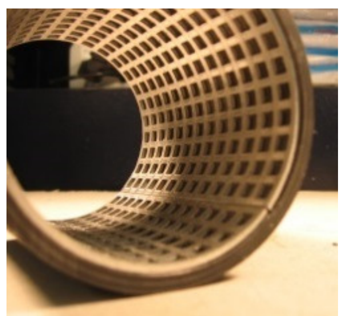
— Propellant and Zinc charges disappeared 100%
— 2/3 of CFRP housing completely disappeared (~ **64%** compared to ~ 50% in phase I design)
— CFRP debris
  — sizes ≤ 80 x 60 mm (compared to ≤ 50 x 50 mm under phase I)
  — both delaminated and full-thickness pieces



Results Phase 2: small scale Test (CFRP alternatives)

- Explosive sheet, inside grid and/or outside pre-fragmentation
  - Inside grid to direct cutting hot gasses, outside scoring to create weak spots when expanding
  - **<u>Fired under water</u>** (fired in air not representative)





Results Phase 2: small scale Test (CFRP alternatives)

- Results
  - 1 mm Semtex versus 4.0 mm CFRP with brittle M55J fibres
    - 2 mm thick 5x5mm inside grid & 1.0 mm deep 5x5mm outside scoring
      - ➢ debris size =< 25 x 25 mm (only grid or only scoring delivered bigger debris sizes)
  - 1 mm Semtex versus 6.7 mm CFRP with tough T700 fibres
    - 2 mm thick 5x5mm inside grid & 1.5 mm deep 5x5mm outside scoring
      - ➢ debris size =< 40 x 60 mm
  - 1 mm Semtex versus 6.7 mm CFRP with brittle M55J fibres
    - 2 mm thick 5x5mm inside grid & 1.5 mm deep 5x5mm outside scoring
      - ➢ debris size =< 20 x 30 mm
    - 2 mm thick 5x5mm inside grid
      - ➢ debris size =< 20 x 30 mm
  - CFRP with brittle fibres breaks up more easily than with tough fibres (regardless of outside scoring)

typical debris sizes
tough versus brittle fibres

Results Phase 2: Summary

- CFRP housing 6.7 mm
  - Self-supporting
  - Designed for **400 bar pressure at 130°C**
  - Produced from tough T700 carbon fibers
- Propellant tube with helical det cord
  - Volume reduced to 1/3 of solid core, improved combustibility
  - Less but more powerful shaped charges (made of Zinc)
  - Overall power reduced to 40% of solid core – NEED TO REDUCE FURTHER
- Closed vessel test: ≤ 80x60mm CFRP debris size
- CFRP with brittle fibres breaks up more easily than with tough fibres