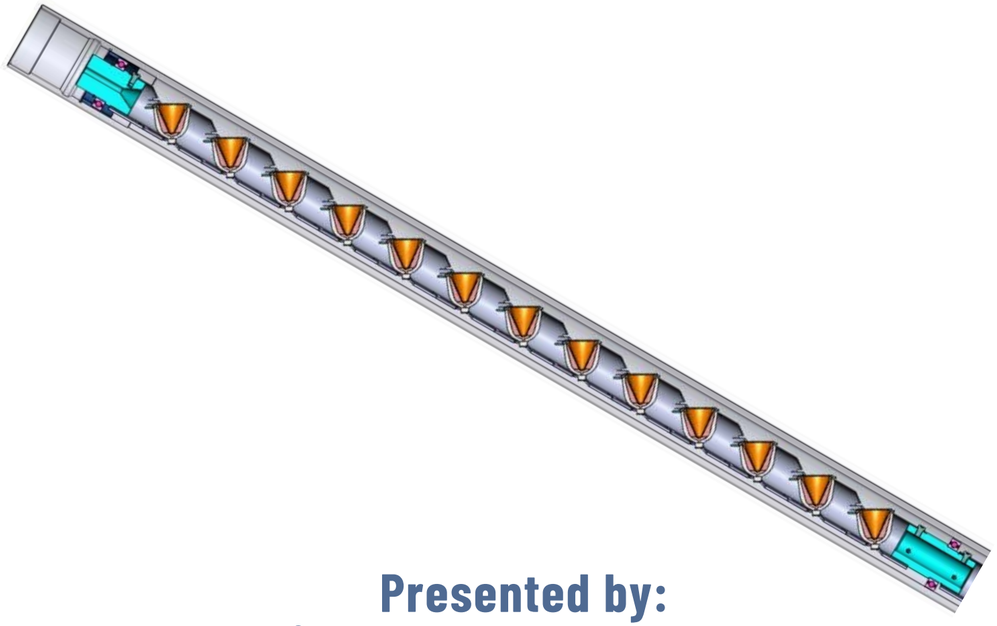
IPS 2024

IPS 24-5.3

Inclined Oriented Gun System for postponement of sand production



Presented by:
Lars Bjarne Nordås, Equinor and Jason Cook, Halliburton

AUTHORS: Lars Bjarne Nordås (Equinor), Bjørnar Kalsvik (Halliburton), Dominic Wong (Halliburton), Jason Cook (Halliburton), Gerald Craddock (Halliburton), Liam Dubs (Halliburton)

Inclined gun project

Agenda

- Challenges and background of the project – Equinor
- Technical development - Halliburton

Background

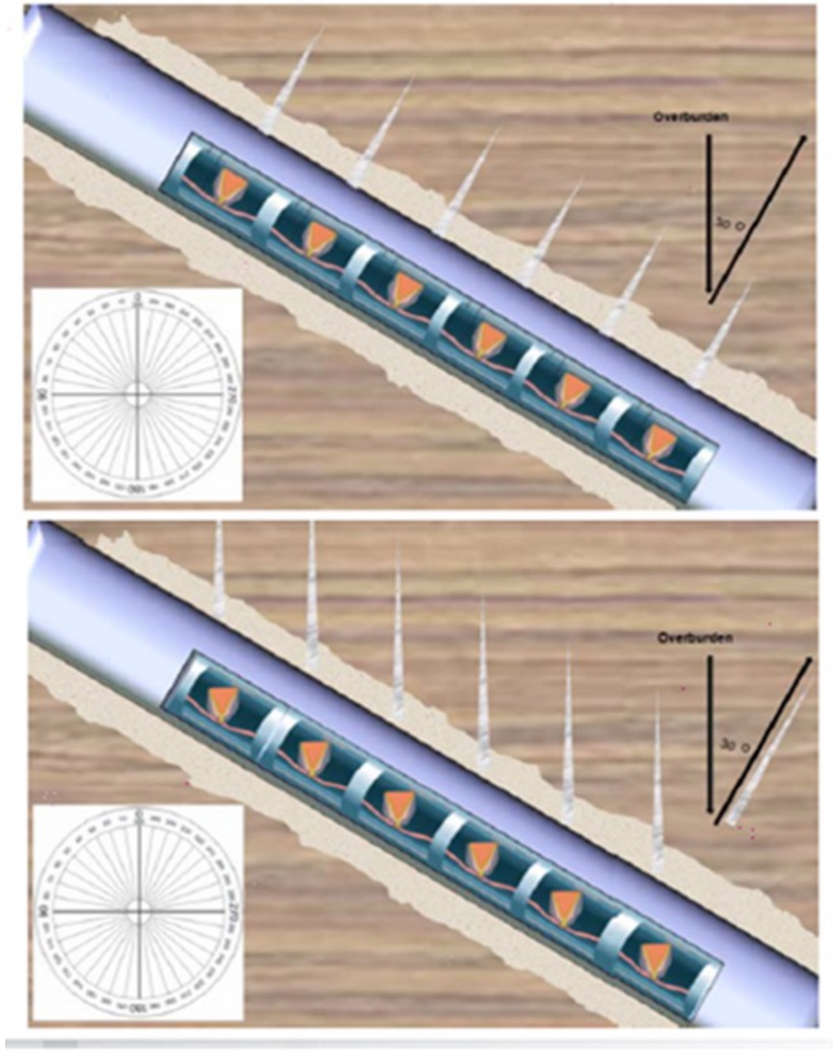
- In-house studies predict that mechanical failure of perforation tunnels may occur after a certain amount of depletion in the weakest, most productive sands. This prediction is borne out by experience and some C&P wells require choking back of production to limit sanding rates when they are producing from heavily depleted regions.

- Consequently, these assets were looking for a possible new technology for improving the structural stability of perforation in sands of a given strength.

- The idea of the new inclined gun technology is that truly vertical perforating tunnels can be achieved even in non-horizontal wells.

- The technology is relevant for fields with near vertical wells prone to sand production as sand screens is not a feasible concept.

- Several fields are relevant for use of the system.



Field-specific challenges

- Deviated wells are prone to sand production once the reservoir pressure is below the formation failure pressure.

- Some wells are not completed with sand screens due to:
  - limited D&W operational window
  - high risk of plugging the screens with particle added drilling mud and the need for water shut-off

- **Field A and B**: At the start of the technology project (2020), 3 out of 11 producers **(field A)** and 2 out of 10 active producers **(field B)** were choked back due to sand production (status changes over time).

- **Field C:** drill and complete in reservoirs with shale intervals (i.e., screen plugging risk) and has choked 6 wells due to sand production (16 active wells total).
  - has an initial pressure of ~440 bar and are prone to sand after about 200 bar depletion in some of the wells.
  - has an intervention strategy to perforate some of the wells in the heel to help lift/increase gas production
  - Many of the heel sections are < 60 deg.(and candidates for the use of the inclined gun system).
  - The field also has vertical wells with a depletion limit where the reservoir breaks and can produce sand. Restrictions topside make it difficult to handle the sands and wells are throttled to avoid erosion or filling of sand in the separator.
  - One well (field trial) were perforated in 2023 (TCP, 60° inclined system, producing as expected, sand free).

When to evaluate inclined perforations for field “A”

Rockfield rock mechanical model

- Inclined perforations have less volume of failed reservoir compared to the other perforation angles evaluated (0° and 10/350° phasing), see bar graphs.
- The advantage is reduced as the reservoir gets more depleted

Inclined perforations developed for field “A”

- The guns are developed and tested for 45° inclination. This means that inclined perforations in field “A” wells (30° incl.) do not shoot vertically,

When can inclined perforations be an advantage for our wells?

- 50 % depletion (410 bar reservoir pressure) - **Clear** indication of advantage
- 80 % depletion (194 bar reservoir pressure) – **Minor** indication of advantage
- Lower reservoir pressure – **Not assumed** to give advantage

Recommendation

- Inclined perforations can be evaluated for wells with reservoir pressure higher than 300 bar.
- Inclined perforations are not expected to decrease sand production in highly depleted reservoir

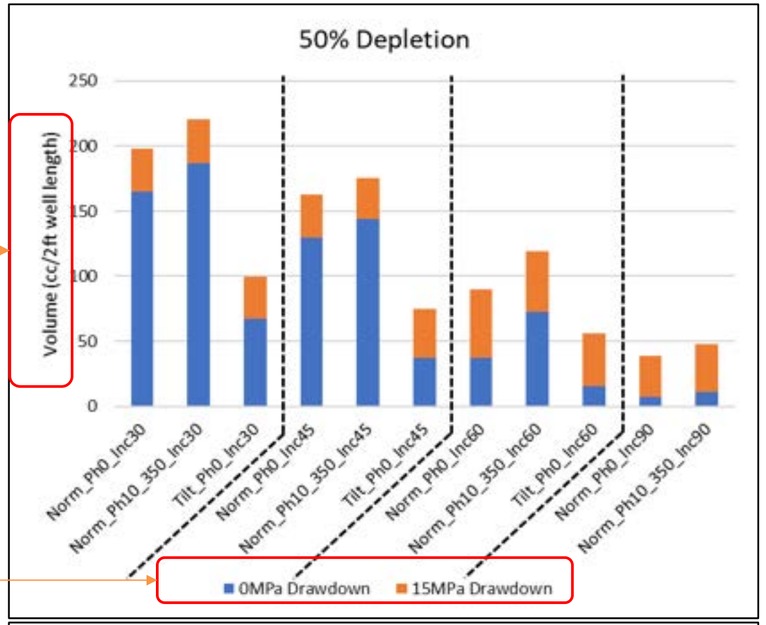
Other factors to consider

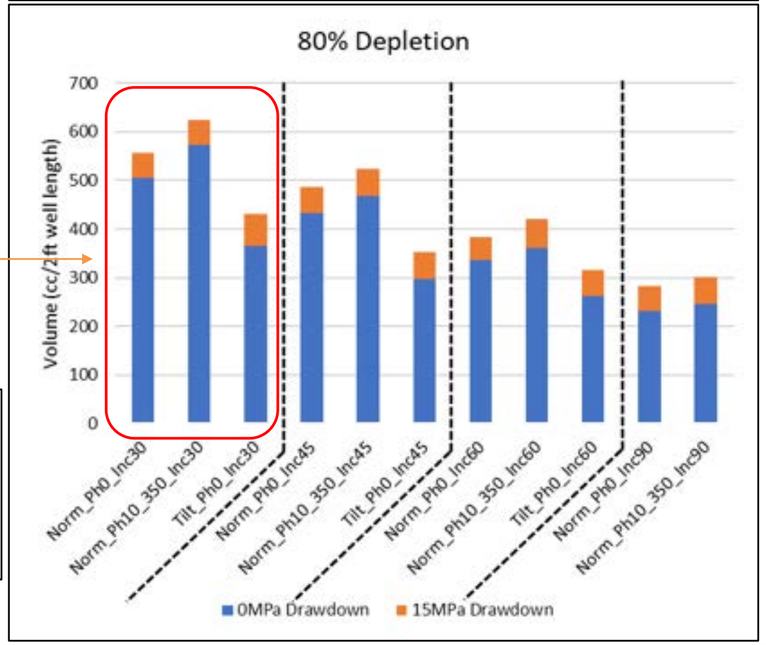
- In addition to formation stresses (influenced by inclined perforations), depletion, drawdown and fluid flow (water) have high influence on sand production.
- Inclined perforations do not penetrate as deep into the formation as standard (perpendicular) perforations. The productivity of the well might therefore be higher for non-inclined perforations.

Volume of failed reservoir
OBS: not produced sand

0 MPa : effect of drilling, completion and perforation
15 MPa: additional effect of production
0 MPa + 15 MPa = total effect

Field “A” conditions (incl 30°)





Explanation bar graphs

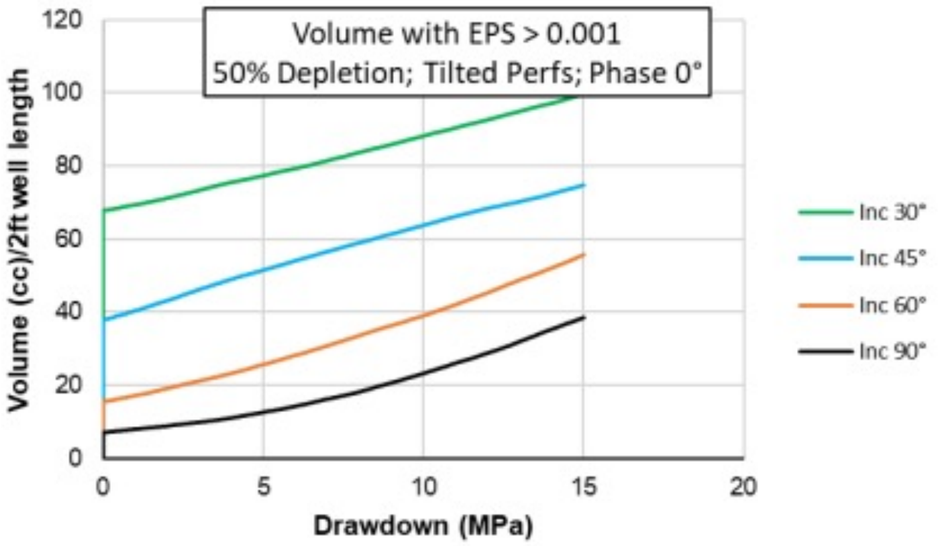
- Blue column: volume of failed reservoir due to drilling and perforation
- Orange column: volume of failed reservoir due to production
- Simulations have been carried out for well angles 30, 45, 60 and 90°

Some result of study, field “A and B”

- Inclined perforations:
  - show **lower levels of damage** comparing to standard oriented perforations regardless of well inclination, phasing and depletion level.
  - **improves structural stability** of perforations compared to perpendicular perforations (wells from 30 -60 deg. Inclination).

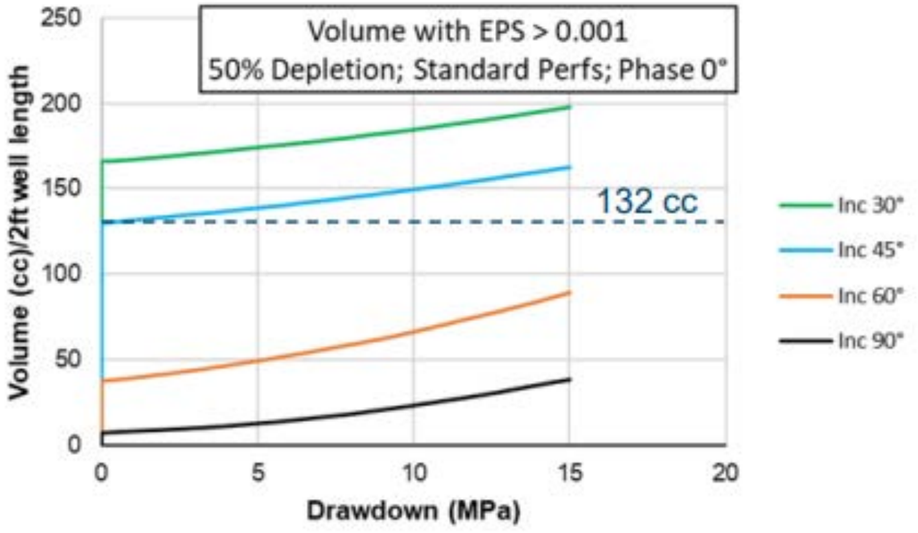
- A **near-vertical well** (30°) is the **less stable configuration** while a **horizontal** well (90°) the **most stable** in terms of perforation stability. This is consistent throughout all base case and
sensitivity simulations.

- For 30° inclined well, tilted/inclined guns will allow an **extra depletion of 110 to 160 bar** compared to todays experience prior to failure of perforation tunnels and potential for sanding.



Total volume of elements with EPS>0.001 / 2 ft length of well

Inclined 0° phasing



Total volume of elements with EPS>0.001 / 2 ft length of well

0° phasing, perpendicular

Some result of study, field “A and B”

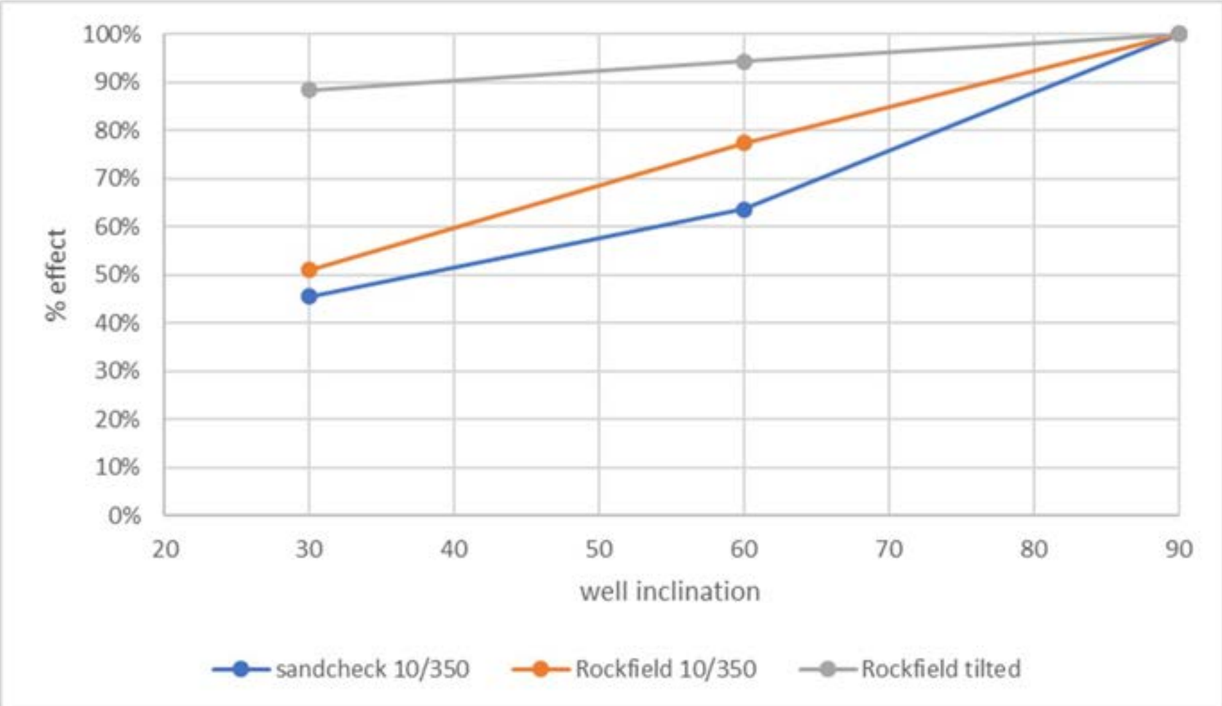
Potential

A rock mechanical model has been prepared to evaluate the potential of inclined perforations. The simulations show that it is possible to deplete an extra 110-150 bar before formation failure. (i.e.,310-350 bar depletion) when applying the technology to near vertical wells (30-45°inclinations).

Increase production

Evaluation of production history show that wells on field A and B can produce respectively ~ 2.5 and 0.5 extra years sand-free with inclined perforations.

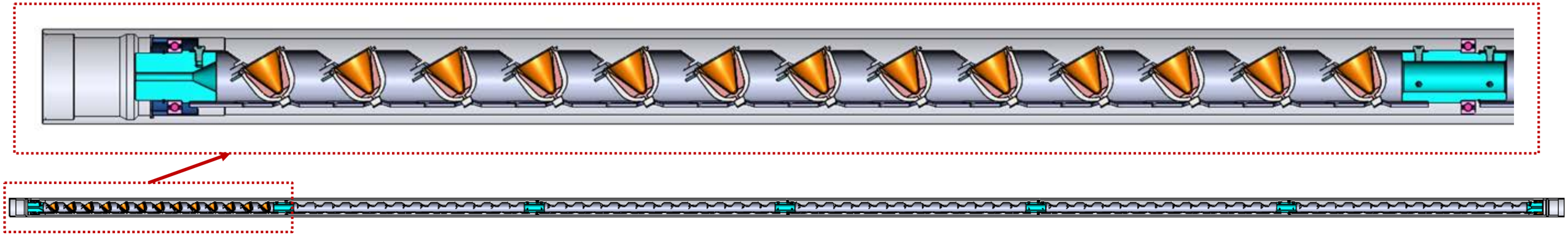
- Extra number of days sand free
- Extra production per well due to no sand production / increased rate from start-up date



Gray line shows the effect of inclined perforation (with 100% effect for a horizontal well) compared to current horizontal perf systems (10/350 deg. Shot phasing)

Inclined Perforating Systems

- Internal orienting charge tube assembly that allows perforating in any direction irrespective of the gun's position relative to the casing
- Custom charge holder based on existing, proven product line
- Inclined system developed for both 45deg and 60deg



Inclined Charge interference Check

CTH

T = 0 microseconds

T = 5 microseconds

T = 10 microseconds

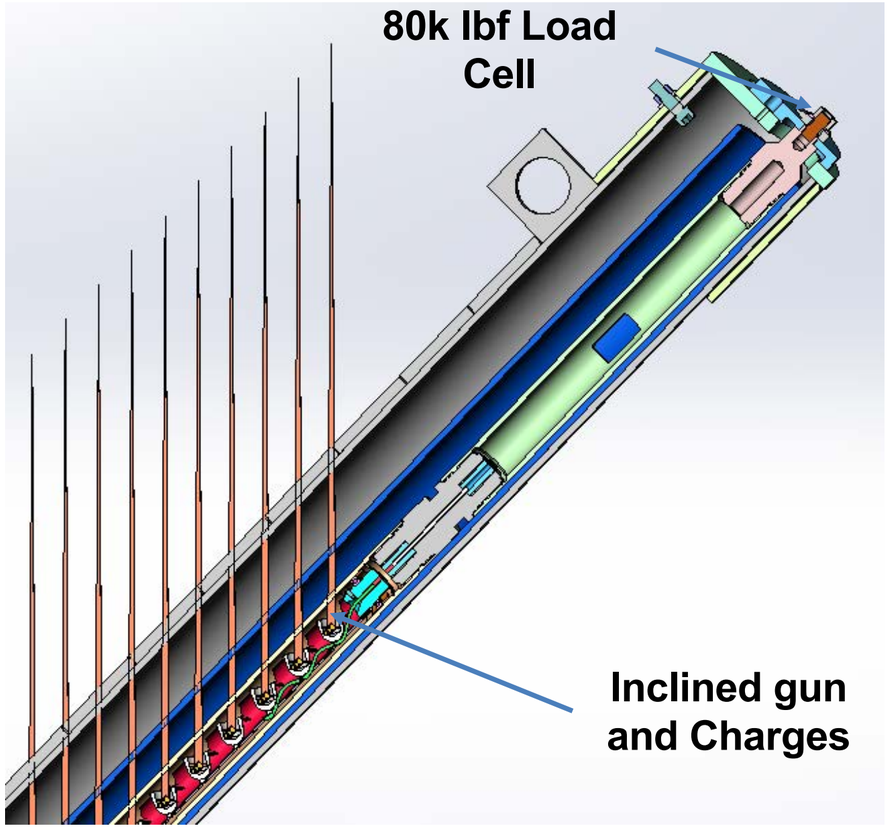
T = 20 microseconds

Flash X-Ray

Barrel Test

Inclined System Air Shot

Inclined System Load Testing Fixture

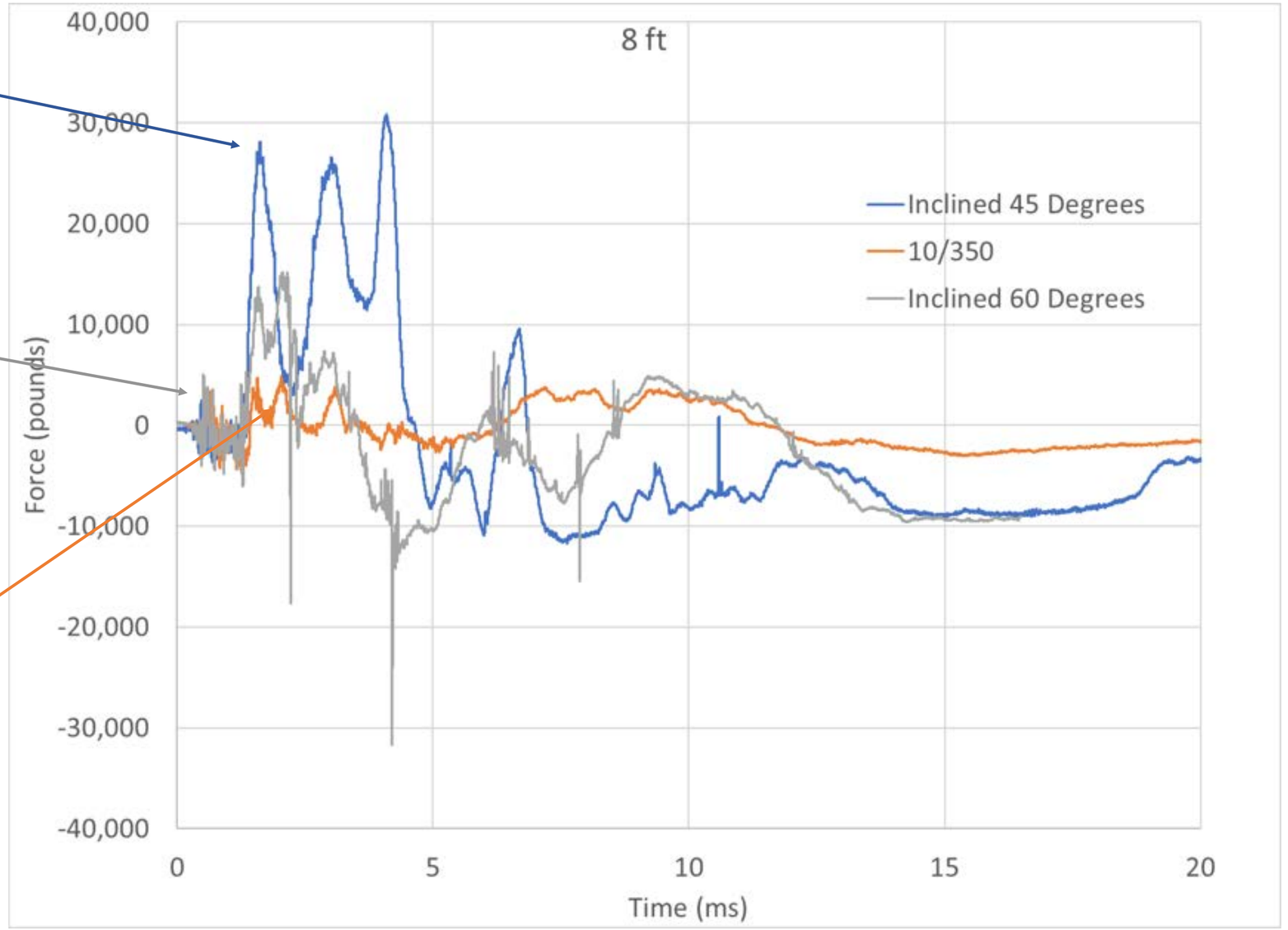


Inclined System Load Testing

8ft 45 Degrees:

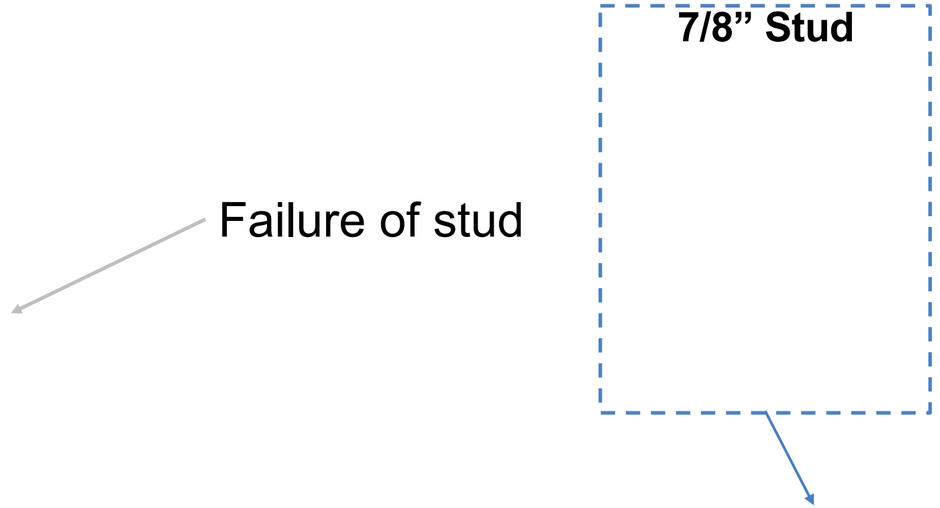
8ft 60 Degrees:

8 ft 10/350:



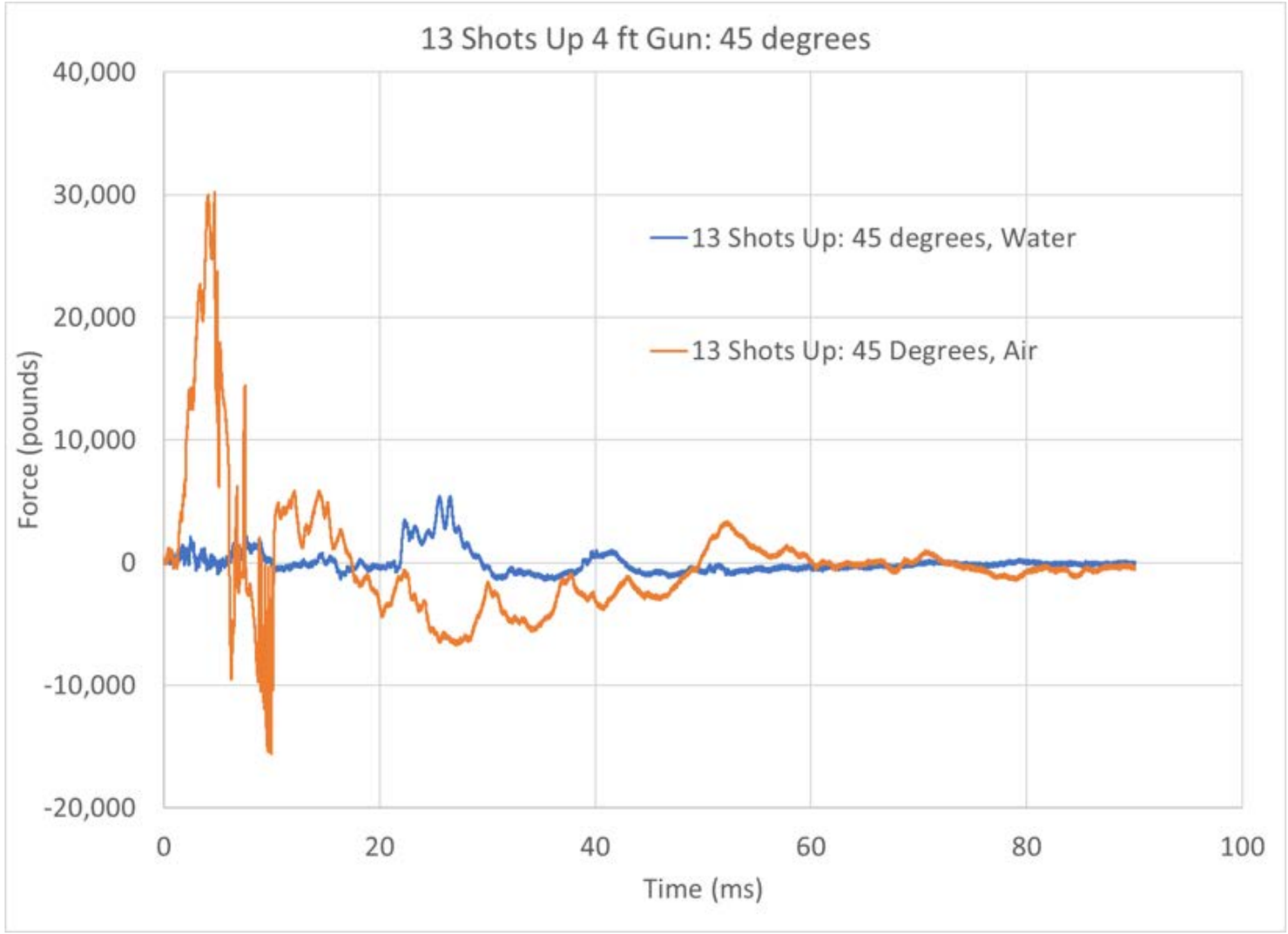
Blink of an eye – 100 to 400 ms

Inclined System Load Testing



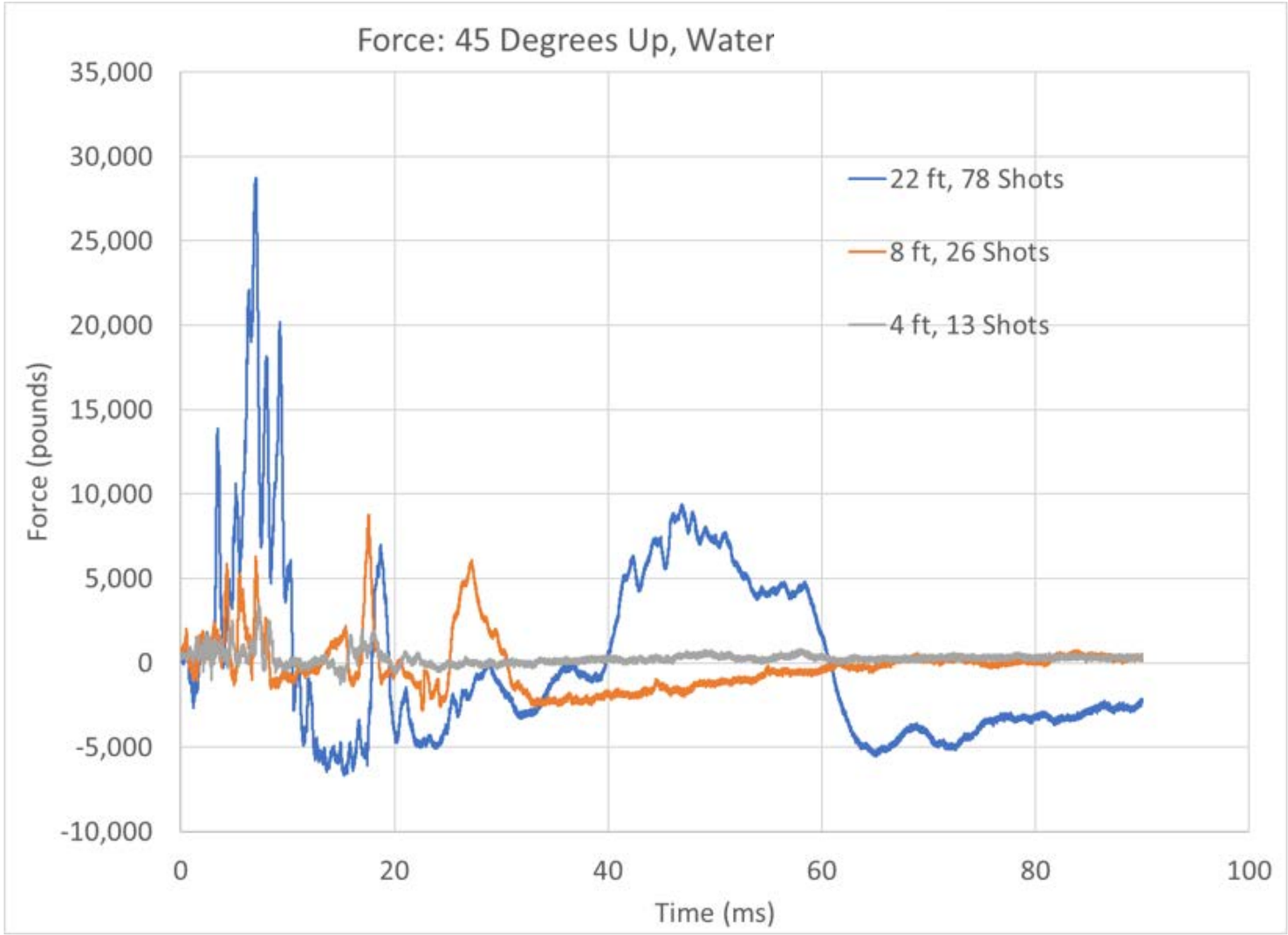
Inclined System Load Testing - fluid and air

- Comparison of fluid and gas
- Load readings were lower in fluid
- In general shots in gas had shorter duration events and earlier, most events in under 10ms
- Shots in fluid had longer events and later in time.



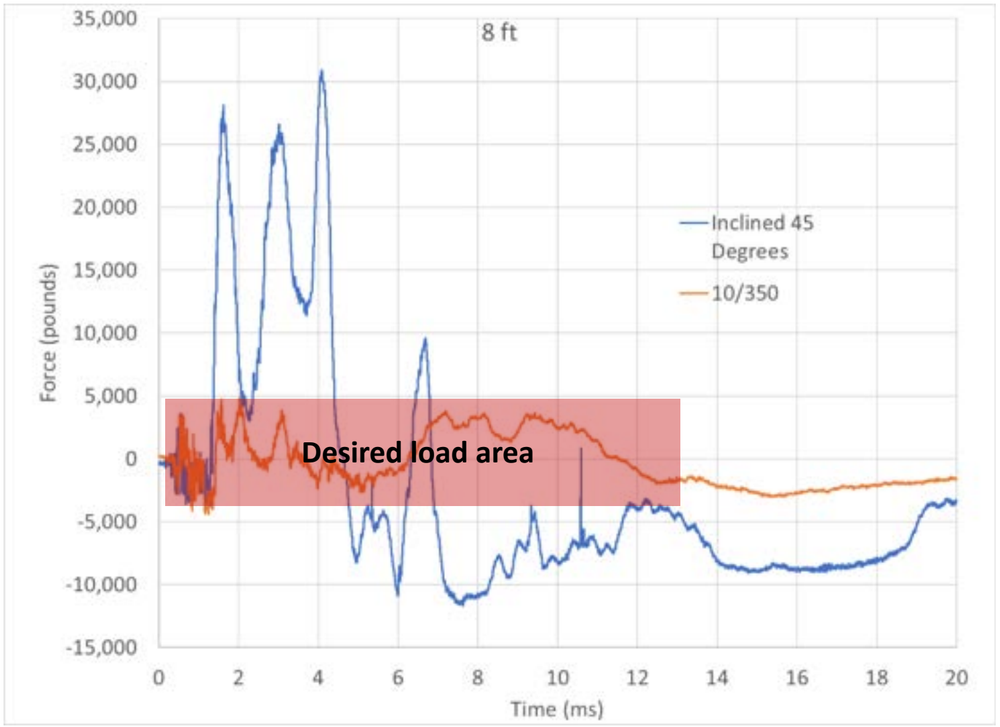
Inclined System Load Testing-Water

- Load readings were lower in fluid
- Shorter length 45deg guns would work in fluid but would still exhibit high loads in gas.



Inclined System summary

- Testing was performed in both fluid and gas
- All testing is baselining to the 10/350 system
- Currently approved for deployment on coil tubing and Tubing Conveyed Perforating applications
- There is an ongoing project in the final stages of development for a wireline variant of the system. The major challenge being to reduce the loads to a point it can be ran on wireline.
- In total over 35 instrumented load tests have been performed



QUESTIONS?

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