An Integrated Scientific Workflow Enables Successful Perforating Operations in Offshore Southeast Asia

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Agenda

- **Background**
- **Description of the Field**
- **Objectives**
- **Scientific Analysis**
  - ✓ Flow Laboratory Testing
  - ✓ Flow Modeling (Productivity / Clean-up)
  - ✓ Job-Design & Modeling
- **Scientific Workflow to Job Execution**
- **Conclusions**

Background

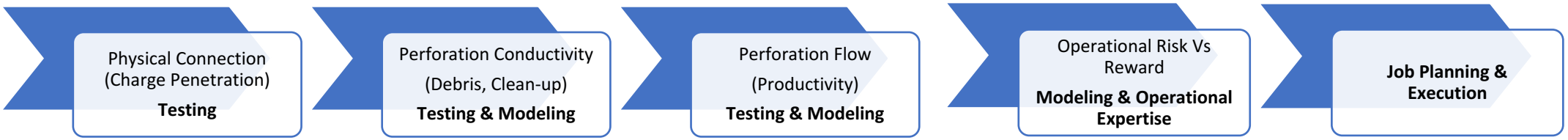
- Integrated technology solutions are key to improving operational efficiency and maximizing hydrocarbon recovery
  - State-of-the-art downhole equipment
  - Laboratory Testing
  - Digital Analysis

- "***Perforating Solutions engineered for optimized completions***"
  - Disciplined and systematic process for job design
  - Integrated testing & modeling workflows
  - Fit-for-purpose equipment (advanced live-well deployment)

Description of the Field

- Maharaja Lela Jamalulalam (MLJ) field situated 50km offshore from Brunei's coast and in approximately 65m of water depth.
- New wellhead platform MLJ3 was installed in 2015, approximately 6km south of the two existing platforms.
- Two types of completion in MLJ south wells: 10Kpsi wells with a 5-1/2" Liner 23# and 15Kpsi wells (HP) with a 4-1/2" Liner 18.9#.
- Tight rock gas formation (Compressive strength ~ 15,000psi, Permeability < 10mD).
- Drilling and completion campaign involving six wells.

Evaluate and optimize the perforating strategy for MLJ3 wells



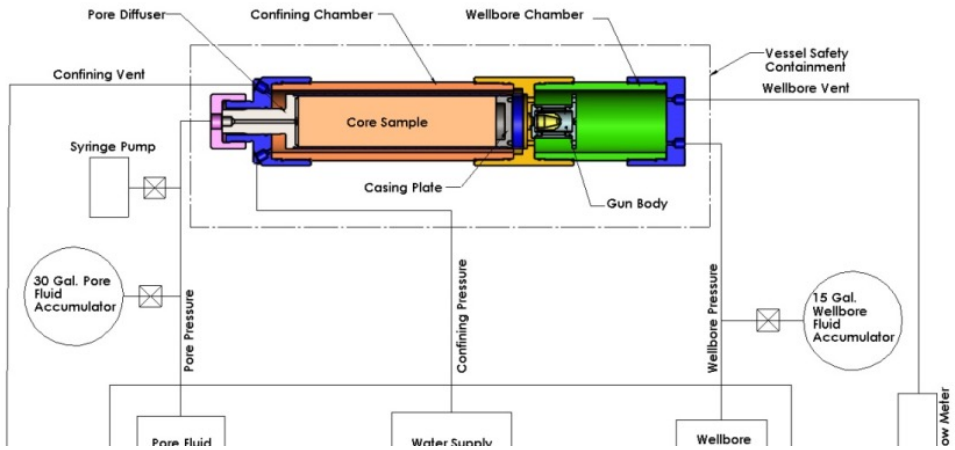
Testing: Flow Laboratory
Modeling: CFD (Computational Fluid Dynamics), Job planning, Dynamic event
Operations: Quality plan, crew competency & training, execution

Flow Laboratory Testing

- Comprehensive testing program (API RP-19B Section 2 & 4) undertaken to provide insight into perforating strategies

- Testing
  - Analog rock (Nugget sandstone)
  - Single/dual/triple casing string
  - Deep penetrating vs Reservoir-driven charges
  - Special HT cement cured at well conditions

- Design factors
  - Shaped charge performance
  - Underbalance and clean-up
  - Influence of wellbore fluids
  - Influence of post-perforating flow time-scales



Flow Laboratory Testing

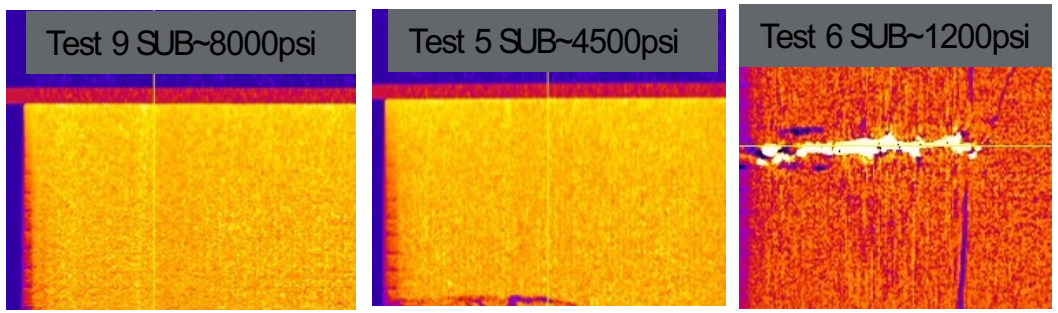
- Transient pressures, tunnel characteristics using CT scanning, productivity and debris mechanisms were analyzed.
- Both shaped charges penetrated through all the casing, cement sheath and into the core.
- Reservoir-driven charges
  - Improved performance with reservoir-driven charges compared to standard charges.
  - Improved core penetration (>50%) and tunnel surface area (~120%)
  - Larger hole sizes (casing/core) with reservoir-driven charges
- Minimal influence of wellbore fluids on charge or flow performance.
- Ability to flow was not affected by post-perforating flow time-scales.

Test ID	Core ID Shaped Charge	Confining Pressure (psi)	Static UB (psi)	Well-bore Fluid	Total Target Penetration (in)	Core Entry Hole Diam.(measured) (in)	Tunnel Debris (gms)
3	13122-01 2818 ZX	11721	4562	1.57 SG CaBr	7.42	0.63	20.0
7	13122-03 2818 ZX (32 days)	11721	4562	1.57 SG CaBr	6.13	0.48	17.7
5	13122-10 2818 ZX	11721	4562	1.0 SG Water	6.28	0.35	21.4
6	13122-05 2818 ZX	11721	1200	1.57 SG CaBr	6.27	0.41	27.0
4	13122-08 3123 DC	11721	4562	1.57 SG CaBr	9.12	0.64	42.6
9	13122-02 2818 ZX	11721	8000	1.57 SG CaBr	6.52	0.31	14.0

Flow Laboratory Testing

- Tunnel clean-up / debris
  - Tunnel debris analysis provided 14gm of debris at 8000psi underbalance compared to 27.0gm at 1200psi underbalance.
  - CT scan analysis of perforated cores demonstrates the reduction of debris as underbalance is increased.

Test #	Static Underbalance (psi)	Weight of Debris (gms)
6	1200	27.0
5	4562	21.4
9	8000	14.0



- **Why computational modeling ?**
  - Core heterogeneity
  - Fracture initiation around tunnels
  - Complement experimental analysis

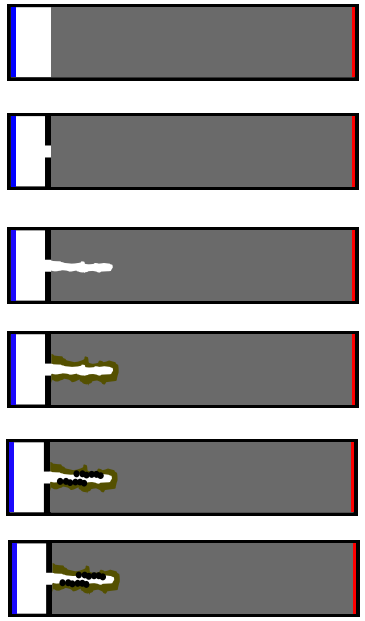
Advanced Computational Modeling

- Smart-CFD approach that utilizes the true perforation tunnel geometry to better predict the flow characteristics around perforations
- Isolate the effects of core heterogeneity / fractures and understand flow characteristics around perforation tunnels only.
- Influence of static underbalance on debris mechanisms (clean-up) and productivity.

CT scan of perforated core
↓
Transform CT scan images to CAD model
↓
Calculate tunnel effective flow area and volumes
↓
Generate fluid mesh from CAD model
↓
Apply Boundary and Initial conditions
↓
Conduct flow simulation
↓
Results and analysis

Advanced Computational Modeling (Productivity)

	Case Layout	Productivity	Productivity Ratio
pre-shot	case 0	6.29 cc/min	1
casing only	case 1	3.15 cc/min	0.50
tunnel	case 2	6.42 cc/min	1.02
damage + tunnel $K_{0,damage} = 0.5*K_{0,native}$	case 3	6.26 cc/min	0.99
debris + damage + tunnel $K_{0,debris} = K_{0,damage} = 0.5*K_{0,native}$	case 4	5.72 cc/min	0.91
debris + damage + tunnel $K_{0,debris} = K_{0,damage} = 0.1*K_{0,native}$	case 5	4.67 cc/min	0.74

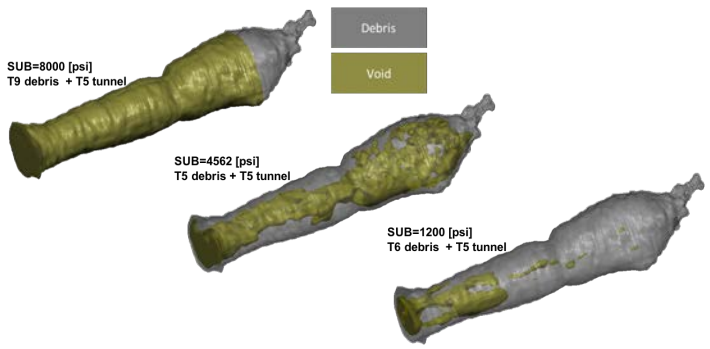


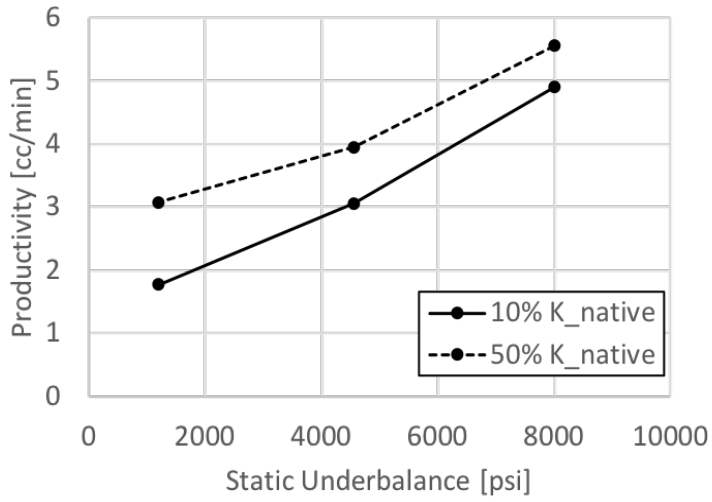
Competing effects of various factors can be easily studied around true perforation geometries

- The casing adds significant resistance to flow, productivity ratio, PR=0.50 (casing only).
- Adding the tunnel leads to slightly higher productivity compared to pre-shot productivity, PR=1.02 (tunnel).
- Damage at 50%/3mm did not significantly reduce productivity, PR=0.99 (tunnel+damage).
- Debris reduces productivity by a noticeable amount, PR=0.91 (tunnel+damage+debris, 50%/3mm).

Advanced Computational Modeling

- Experimental analysis showed that higher static underbalance provides reduced debris, which indicates better clean-up of the tunnel.
- Unique approach where the tunnel geometry was kept constant and debris patterns from tests at different static underbalances were digitally incorporated into the tunnel.
- Consistent and quantitative analysis of debris and showed the overall effect static underbalance has on productivity.



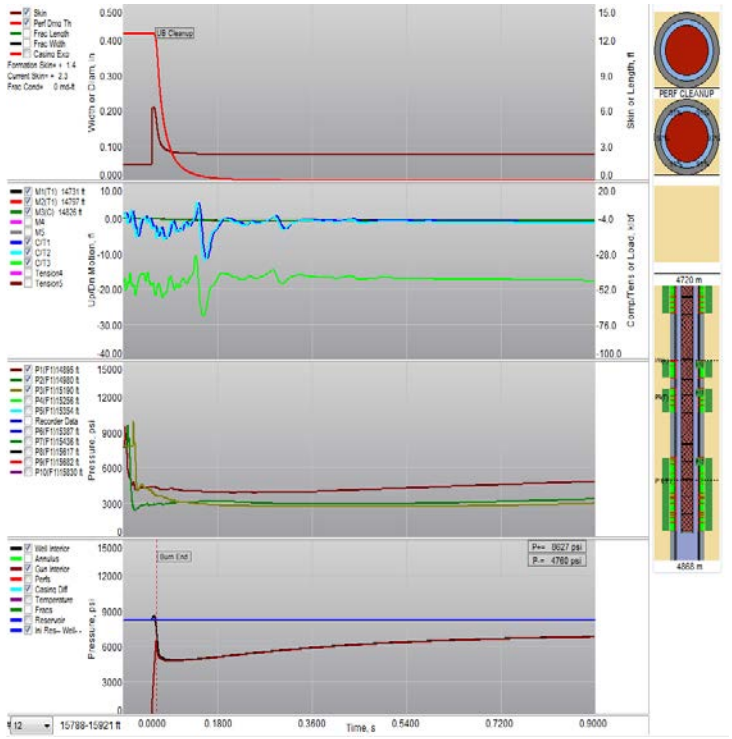


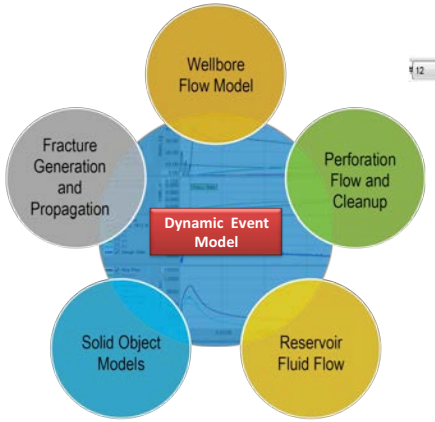
Advanced Computational Modeling

- Modeling software to conduct force analysis and wellbore hydraulics modeling for coiled tubing deployment.

- Dynamic event modeling
  - Gun shock physics due to perforating event
  - Risk evaluation and mitigation
  - Underbalance and clean-up optimization

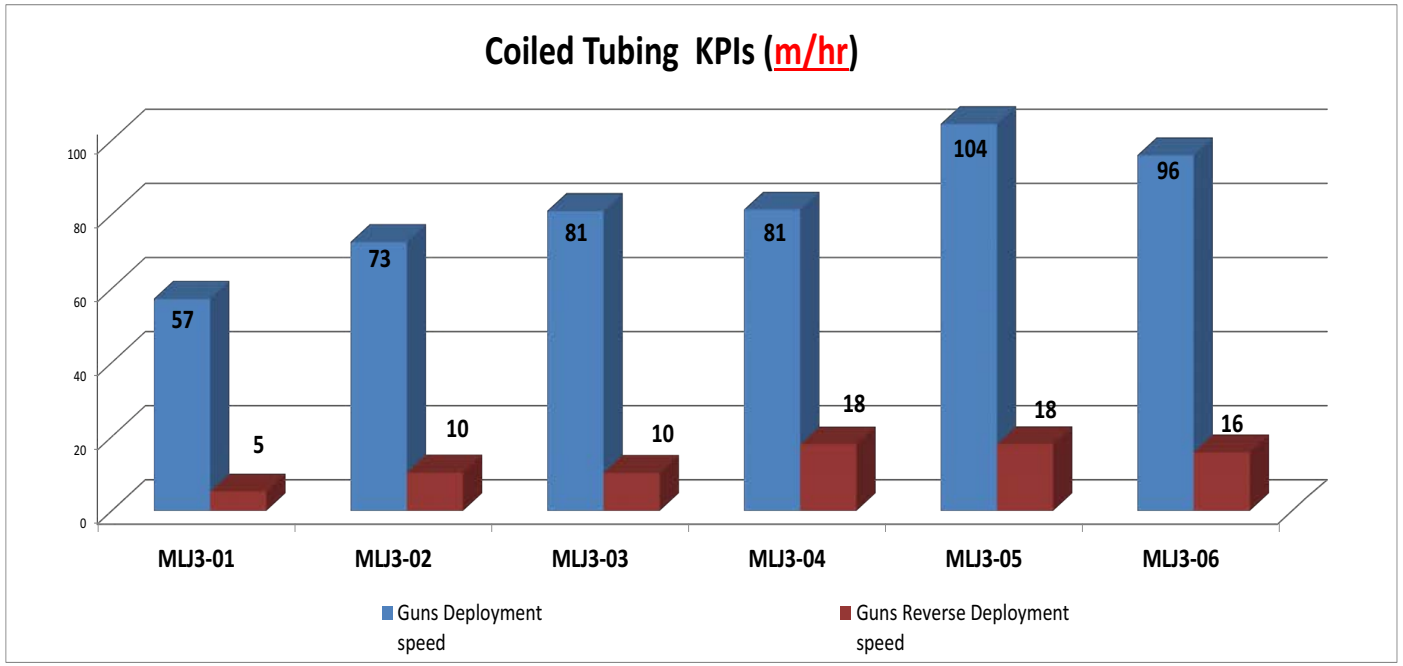
- Upscale from laboratory to well-scale job design





From Scientific Workflow to Job Execution

- Six wells delivered safely and within timeframe and budget.
- Four well interventions successfully completed with enhanced production.
- Advanced live-well deployment system successfully used for deploying ~300 guns
- Continuous improvement process that led to improved operational efficiency with each well.



From Scientific Workflow to Job Execution

MLJ3-05 well

- Execution of an optimized perforating strategy led to the well delivering excellent productivity (more than expected). Well is currently flowing ~**40%** above its planned production capacity.
- **Highest underbalance of 5,600psi** achieved due to the insight from in-depth scientific testing and modeling efforts.
- **Shortest and fastest completion** duration of 22 days.
- **Lowest NPT Completion** since beginning of the campaign, 0.7 days throughout the entire completion duration (3.4%)

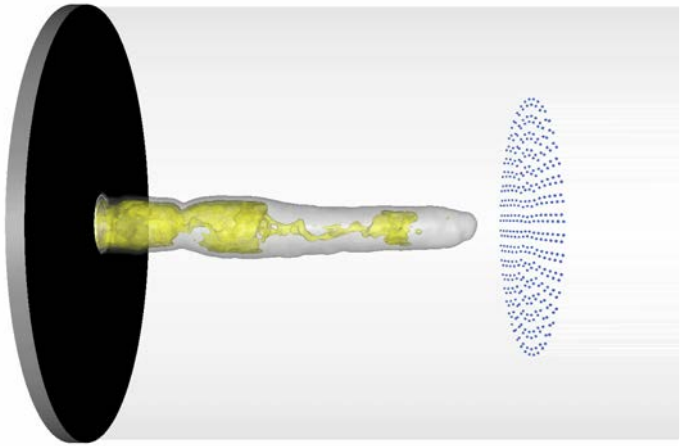
MLJ3-06 well

- Reservoir-driven charges used for the entire perforation interval.
- Well currently flowing as per expectations.

Conclusions

- Comprehensive testing and modeling program provided insight into the perforating strategies for the MLJ3 well campaign.
- All MLJ south wells were successfully perforated, establishing communication between wellbore and targeted reservoir.
- The productivity on the wells was determined to be as expected or exceeded expectations (in particular, MLJ3-05).
- Significant operational benefits like reduced NPT, faster deployment of guns etc. were also accomplished through comprehensive planning and collaboration between the operator and service provider.
- Reference: OTC-28693 for more details

	Testing	CFD	Job-Model
Shaped charge Performance	X	N/A	N/A
Underbalance Mechanism	X	X	X
Hold time effect	X	N/A	N/A
Gun Size effect	X	X	X
Wellbore Fluid	X	N/A	X
Productivity	X	X	N/A
Risk Evaluation	N/A	N/A	X



Acknowledgements / Thank You / Questions

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QUESTIONS? THANK YOU