



Dynamics of a Completion String in a Fluid-Filled Well Bore

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**Allan Zhong
Frederic Felten**

HALLIBURTON

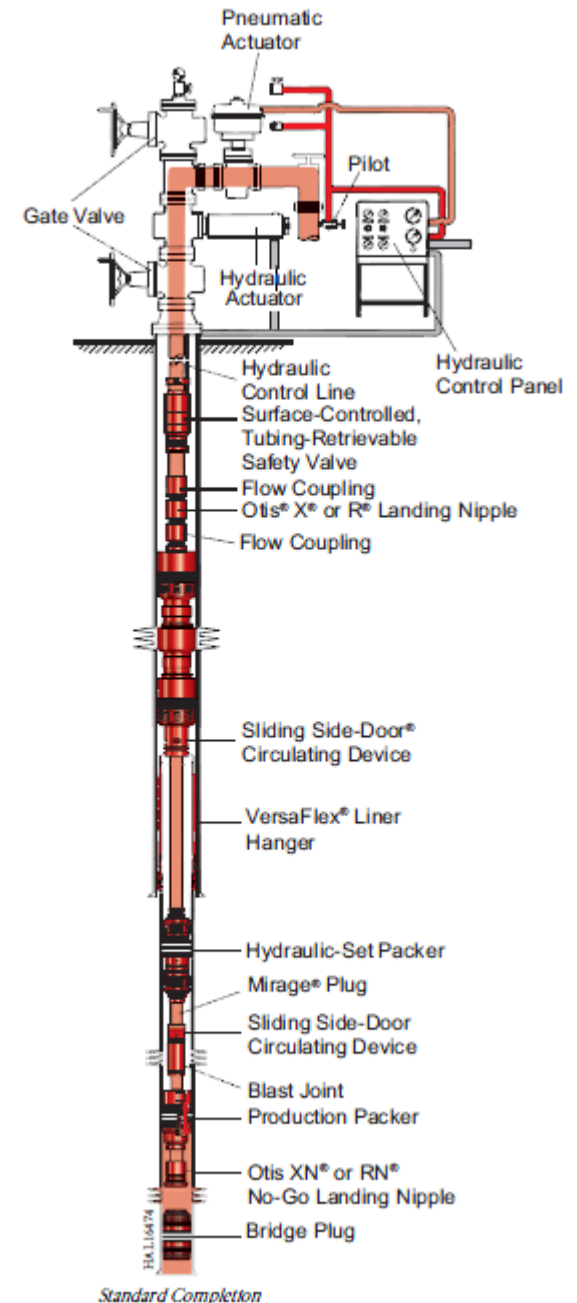
Outline

1. Background
2. Fluid Mechanics Considerations
3. The model
4. Dynamics of Completion Strings
5. Conclusions and Remarks
6. Acknowledgement

Background

In oil and gas well field operations, downhole completion tasks require overpull or slack off on the tubing string at the rig floor. For example, after a completion tool is run to position, typically overpull or slack off is used to overcome locking and locating mechanisms

- induce significant sudden movement of the completion tubing string
 - potentially undesirable events, e.g. packer element swab off



Background

Evaluating the completion string dynamics involves the influence of fluids

Full 3D, two-way fluid structure interaction analysis is prohibitive for both cost and time

Background

ABAQUS/Aqua was used before

- successfully applied to tubing slack off
- **limitation** – cannot account for the influence of wellbore size

Background

Major improvements over previous work:

- account for influence of wellbore through analytical solutions in fluid mechanics
- account for influence of flow restriction via computational fluid dynamics

Background

Case Study

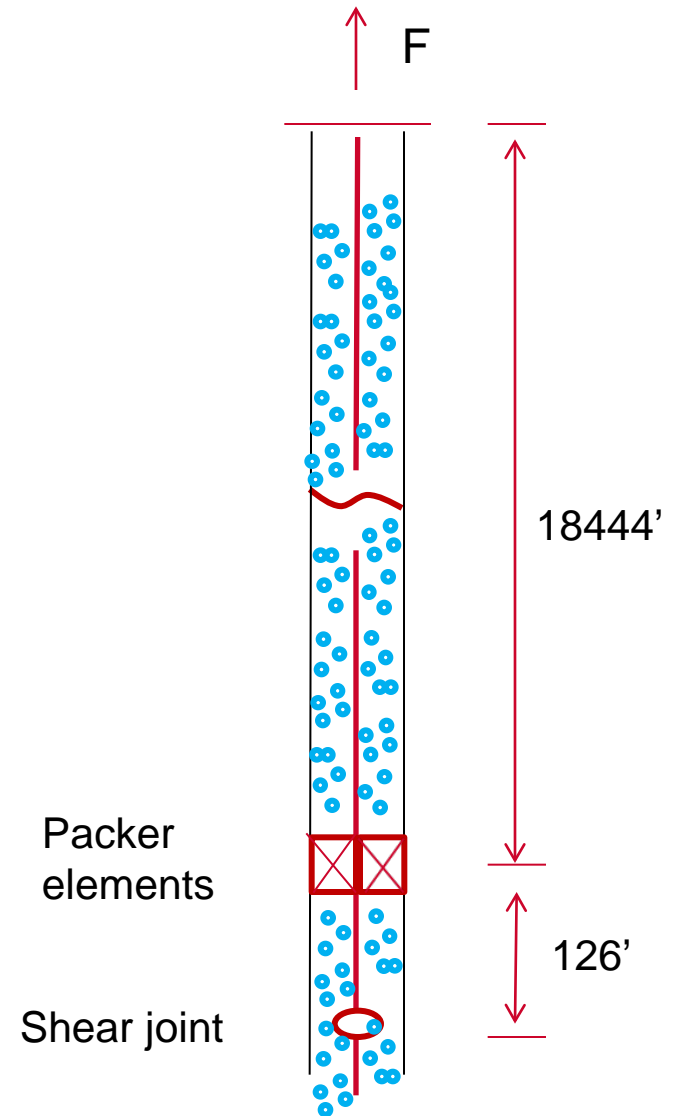
Casing is 9-7/8-in. 68 lb with nominal I.D. of 8.617-in. Tubing is 5-1/2-in. 26 lb with nominal O.D. of 5.5-in. and nominal I.D. of 4.485-in.

In the tubing string:

- Packer is located 18,444 ft from surface (rig floor). Packer O.D. is 8.350-in. and element length is approximately 11 ft long (assume packer I.D. is same as tubing).
- a short distance below the packer is the shear joint, located at 18,570 ft from surface (rig floor) – open end.

Wellbore fluid: 14.2 lb CaBr.

Shear joint ratings: 15k lbf, 45k lbf, and 75k lbf



Background

Objectives of this study:

- 1) Understand completion string dynamics during operations
- 2) Determine operation parameter (overpull) range so that swab-off will not occur for a given packer element design

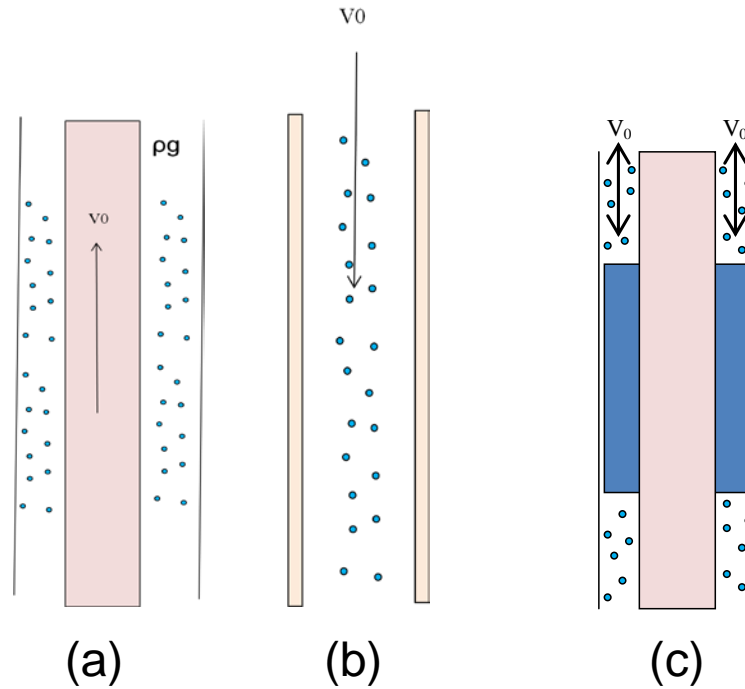
Fluid Mechanics Considerations

Fluid-structure interactions:

Three sources contribute to total drag force on the system:

- ***tangential drag on the OD*** of the tubing string due to the annular flow
- ***tangential drag on the ID*** of the tubing string due to the internal pipe flow
- ***drag due to the fluid flow around the packer elements***. When the tubing string moves up or down, the packer elements provide substantial resistance to the flow and pipe motion

Fluid Mechanics Considerations



(a) Annular flow

(b) Internal flow

(c) Flow around Packer elements

Fluid Mechanics Considerations

The drag forces per unit length due to the internal and annular flow, away from the restrictions

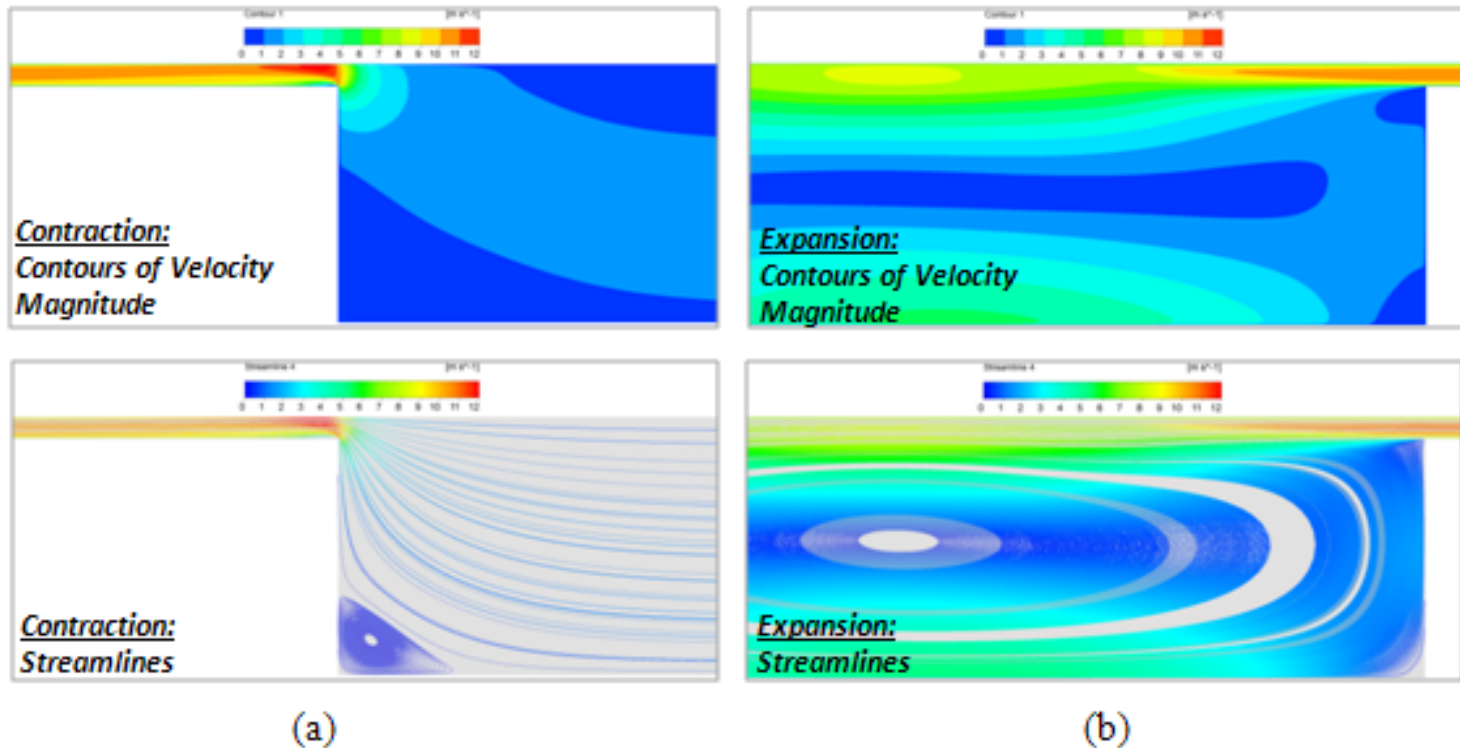
$$\text{Drag}_{\text{Tubing}} = \underbrace{\left(\frac{\mu V_0}{r_0 \ln\left(\frac{r_1}{r_0}\right)} \right) \cdot \pi \cdot OD_{\text{Tubing}}}_{\text{Annular flow}} + \underbrace{\left(\frac{1}{2} \rho V_0^2 \cdot \frac{0.0791}{\text{Re}_{ID}^{1/4}} \right) \cdot \pi \cdot ID_{\text{Tubing}}}_{\text{Internal flow}}$$

Where r_0 is the tubing radius at OD, r_1 is the casing radius at ID, V_0 is the tubing speed, ρ is the density and μ is the dynamic viscosity of the fluid. Note that the shear varies linearly with the moving pipe velocity.

Note: need to use this drag formula instead of ABAQUS/Aqua built drag formula

Fluid Mechanics Considerations

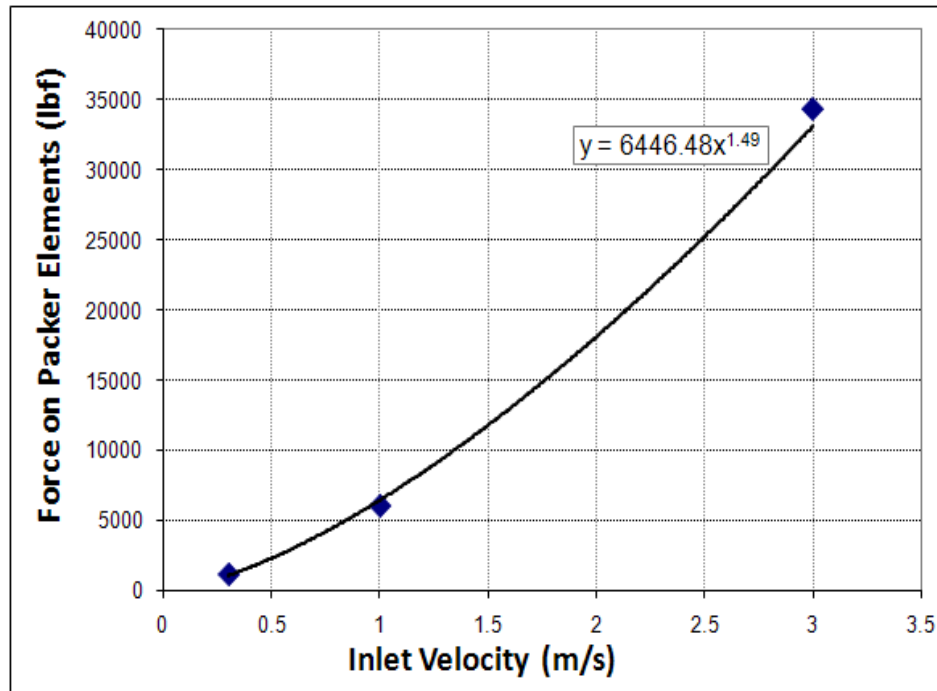
The drag forces due to the flow restrictions from packer elements



Flow behavior (a) near front restriction, (b) near back expansion

Fluid Mechanics Considerations

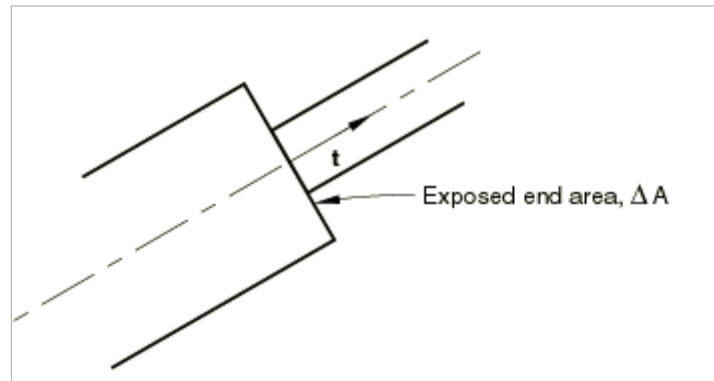
The drag forces due to the flow restrictions from packer elements



Force on packer elements at different flow velocity

Fluid Mechanics Considerations

The drag forces due to the flow restrictions from packer elements



The drag is accounted for in the ABAQUS/Aqua by quantifying this “drag” as a point drag as defined in the Abaqus Theory manual

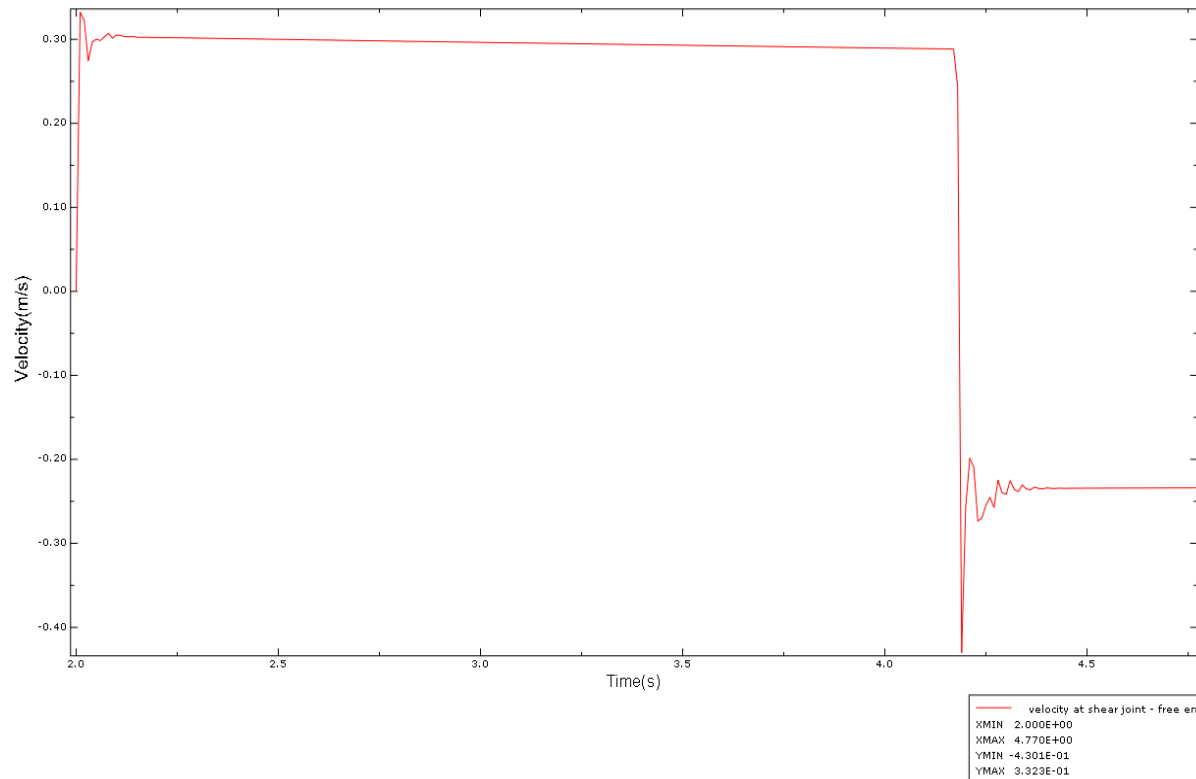
The Model Formulation

- 1) Pipes are modeled as beams with proper cross section profiles.
- 2) Interaction between pipe and fluid is approximated by (buoyancy, drag) fluid force acting on pipes via Abaqus/Standard, Abaqus/Aqua.
- 3) Well bore size was considered in drag calculation, as well as flow rate calculation.
- 4) Material damping of steel pipe is assumed to be very small. Environmental damping to the pipe string due to fluid is accounted for from fluid loading.
- 5) Simulation of the tool release process:
 - Hold tubing string at the top by tubing total weight in fluid.
 - Fix the bottom; overpull the string at top to 15kips, 45kips or 75kips (the force is converted to Newton in the models).
 - When overpull reaches the designated value, fix top, and let the bottom go.
 - Investigate the dynamics of the tubing string **in fluid**.

The tool release process is analyzed via (implicit) linear dynamic elasticity

Dynamics of Completion Strings

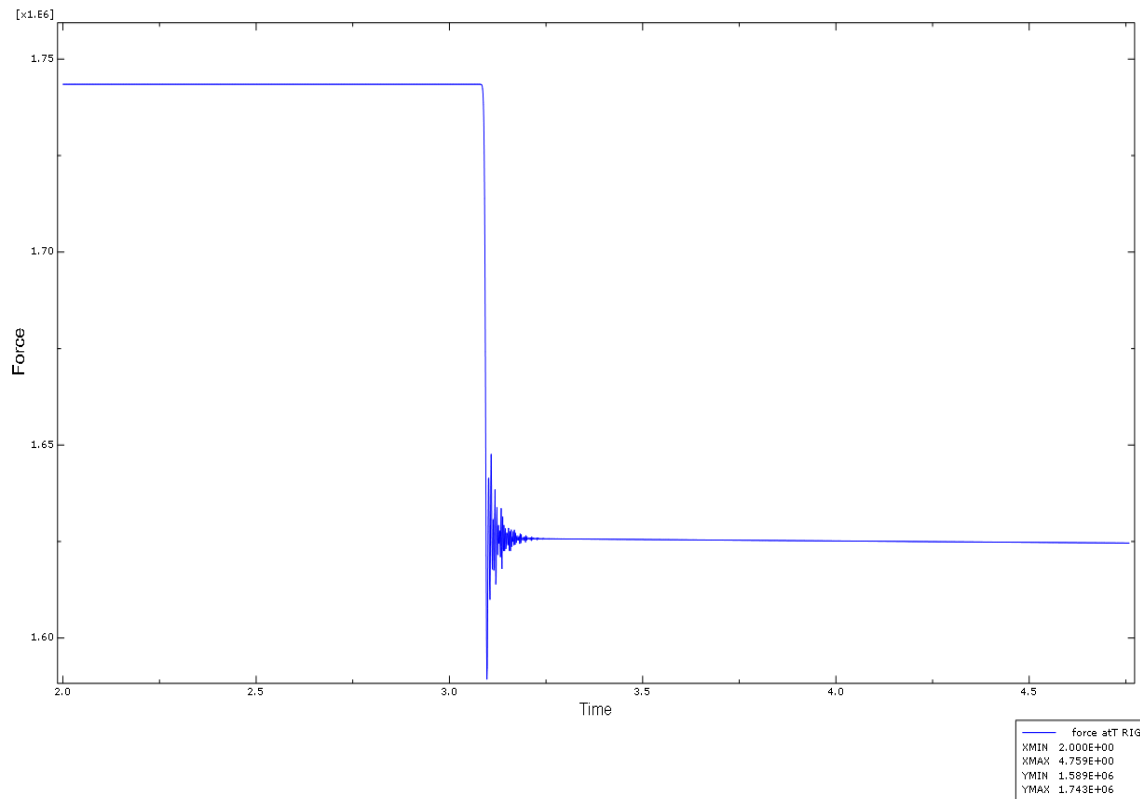
Shear joint rating 15kips



Velocity at shear joint

Dynamics of Completion Strings

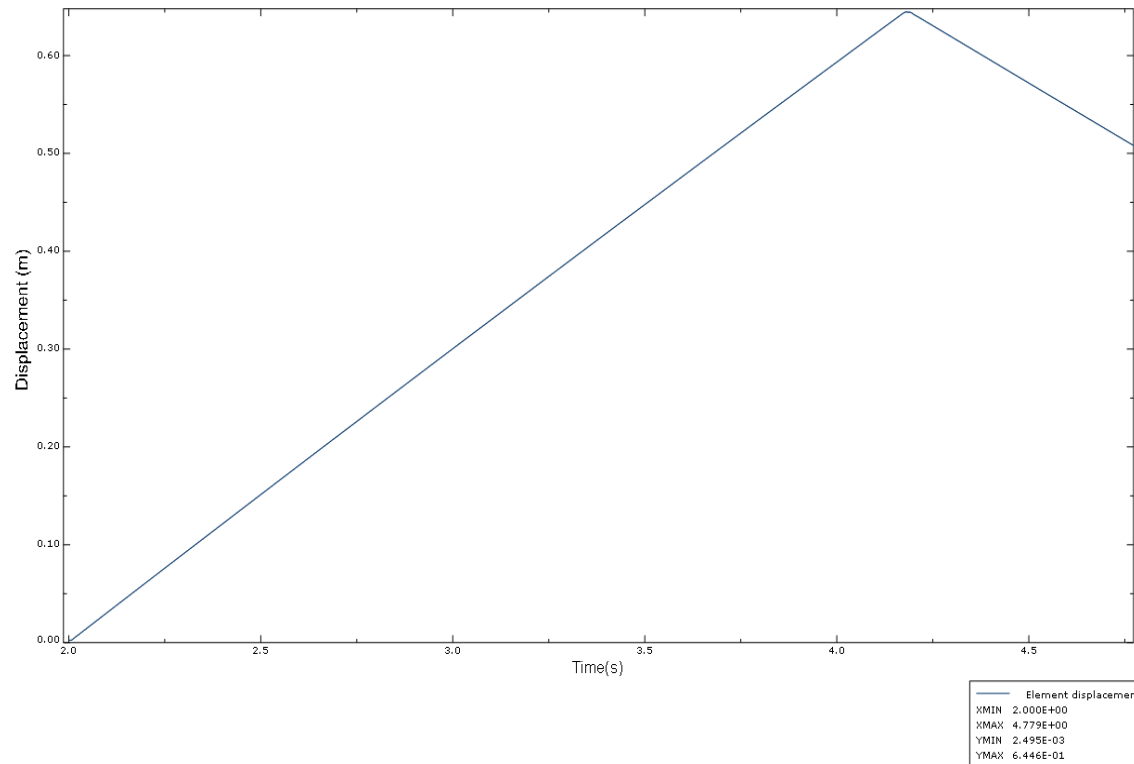
Shear joint rating 15kips



Force at Rig Floor

Dynamics of Completion Strings

Shear joint rating 15kips

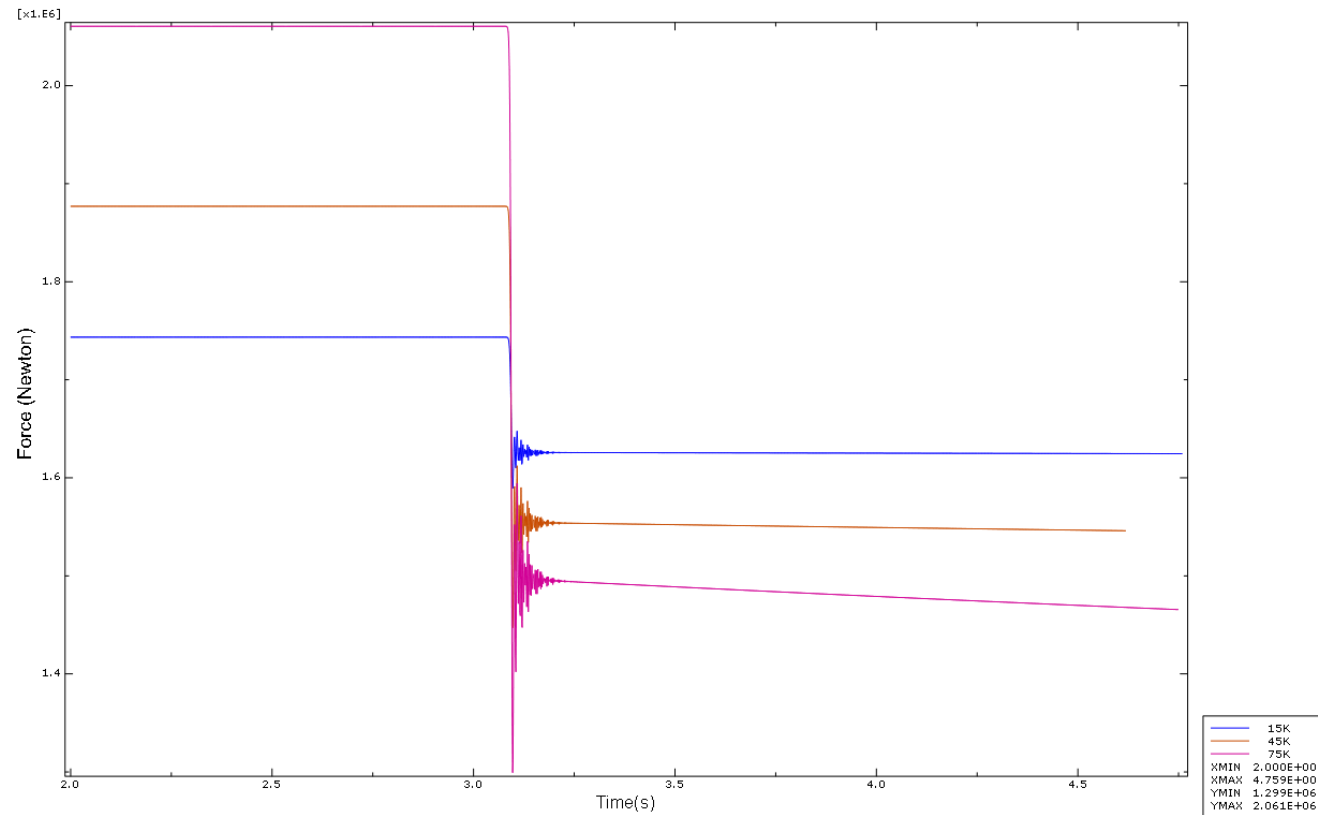


Element movement

Dynamics of Completion Strings

Effect of Overpull Magnitude

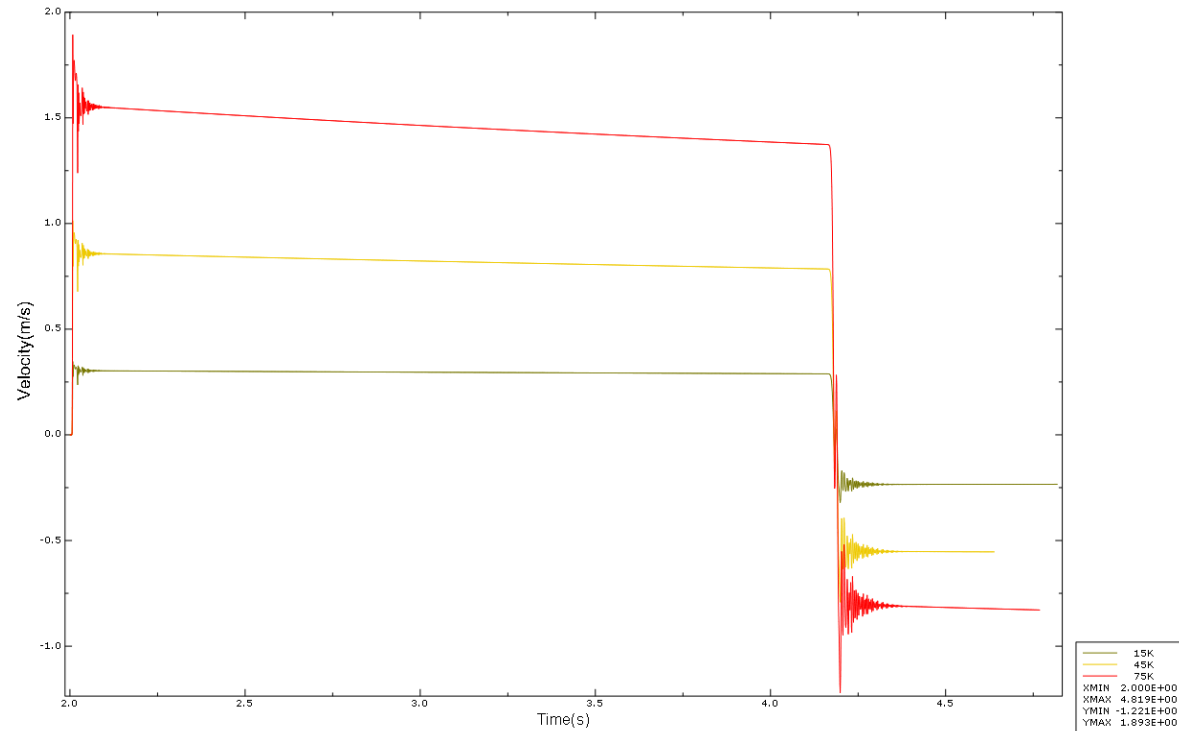
Weight + over pull



Effect of overpull magnitude on rig floor force

Dynamics of Completion Strings

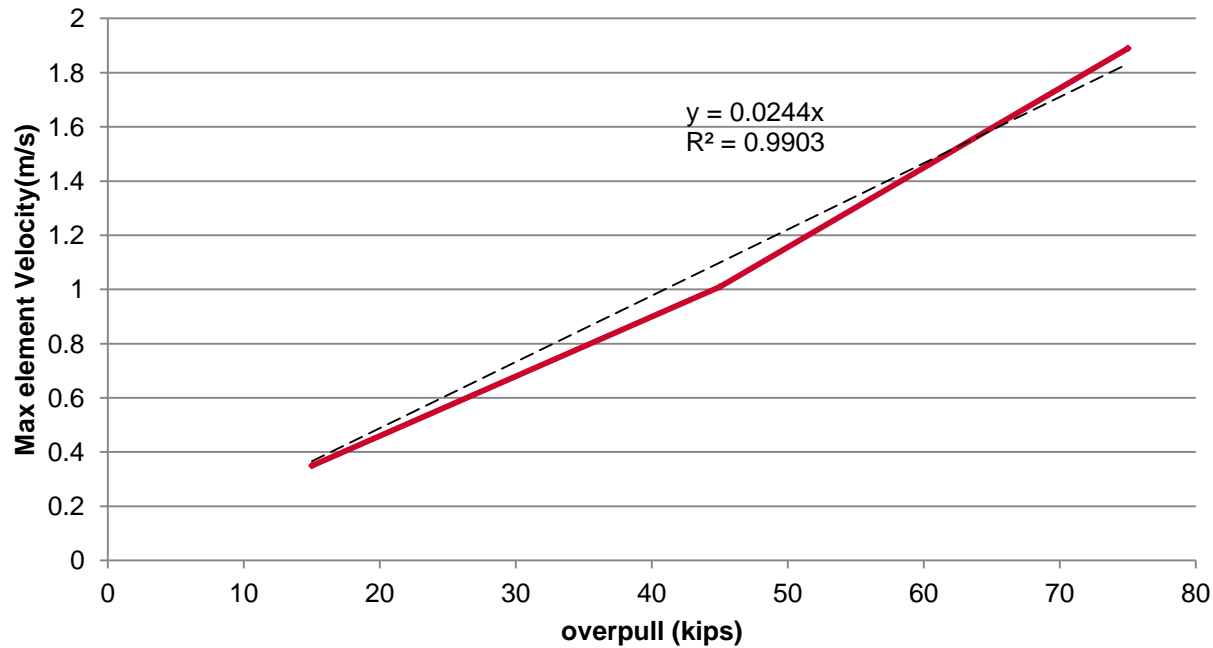
Effect of Overpull Magnitude



Effect of overpull magnitude on element velocity

Dynamics of Completion Strings

Effect of Overpull Magnitude



Relation between max element velocity and overpull magnitude

Dynamics of Completion Strings

Swab-off Evaluation – compare flow rate at elements to critical flow rate

Flow rate at element under different overpull

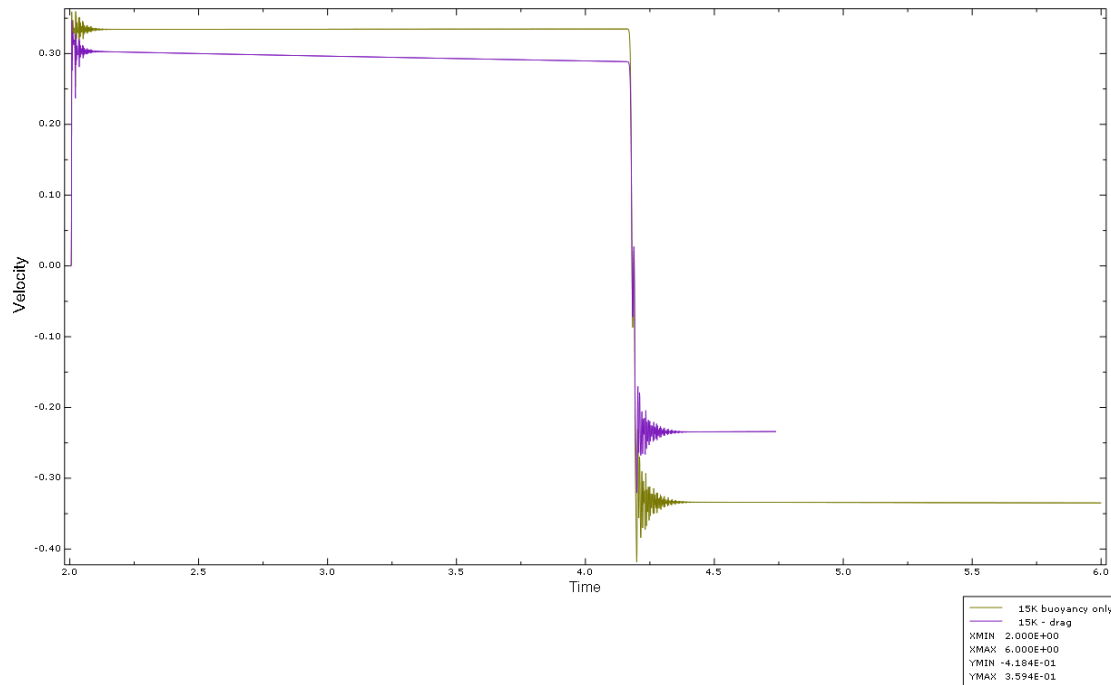
overpull (kips)	15	45	75
element max velocity (m/s)	0.35	1.01	1.89
equivalent flow rate (barrel per minute, bpm)	1.36	3.95	7.36

Typically, the critical flow rate that leads to swab off for a given element design in a given size of casing or wellbore is determined from flow tests.

Assuming that the critical flow rate in this application is 7 bpm, then the maximum overpull that can be applied to the tubing is 72.7 kips without causing element swab off during the tool unlocking process (shear joint shearing).

Dynamics of Completion Strings

Sensitivity of model prediction to different assumptions



Element Velocity due to shearing of shear joint, with and without drag in the model

Dynamics of Completion Strings

Sensitivity of model prediction to different assumptions

	overpull (kips)	15	45	75
In fluid with drag	element max velocity (m/s)	0.35	1.01	1.89
	equivalent flow rate (bpm)	1.36	3.95	7.36
In fluid without drag	Element max velocity	0.42	1.26	2.06
	Equivalent flow rate buoyancy only (bpm)	1.63	4.88	8.02
In air	Element max velocity	3.8	4.5	5.5
	Equivalent Flow rate in air (bpm)	14.4	17.5	21.4

- Obviously, the “in air” model is not suitable
- The proposed approach, to account for drag due to fluid flow in an annular area and at flow restriction, can properly predict completion string dynamics efficiently, providing a quantitative estimation of dynamic effects.

Summary

- “In Air” model is not suitable for analysis of string dynamics in fluids
- An extension of Abaqus/Aqua to an internal flow problem is proposed and applied to the study of dynamics of completion tubing strings in fluid filled wells. The predictions from the model correlate with general field experience
- The proposed approach should provide an effective and efficient method for the study of dynamics of a completion string or any other tool string in wellbores.

Acknowledgement

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