Pipeline Inspection Tool Virtual Prototyping

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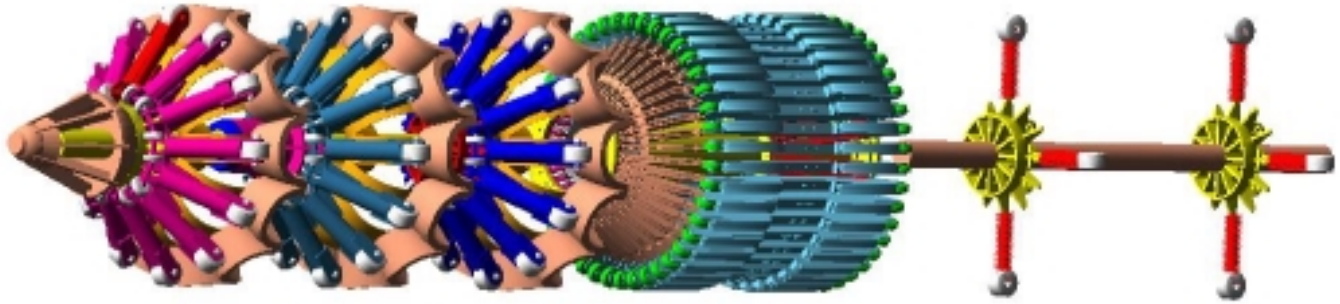
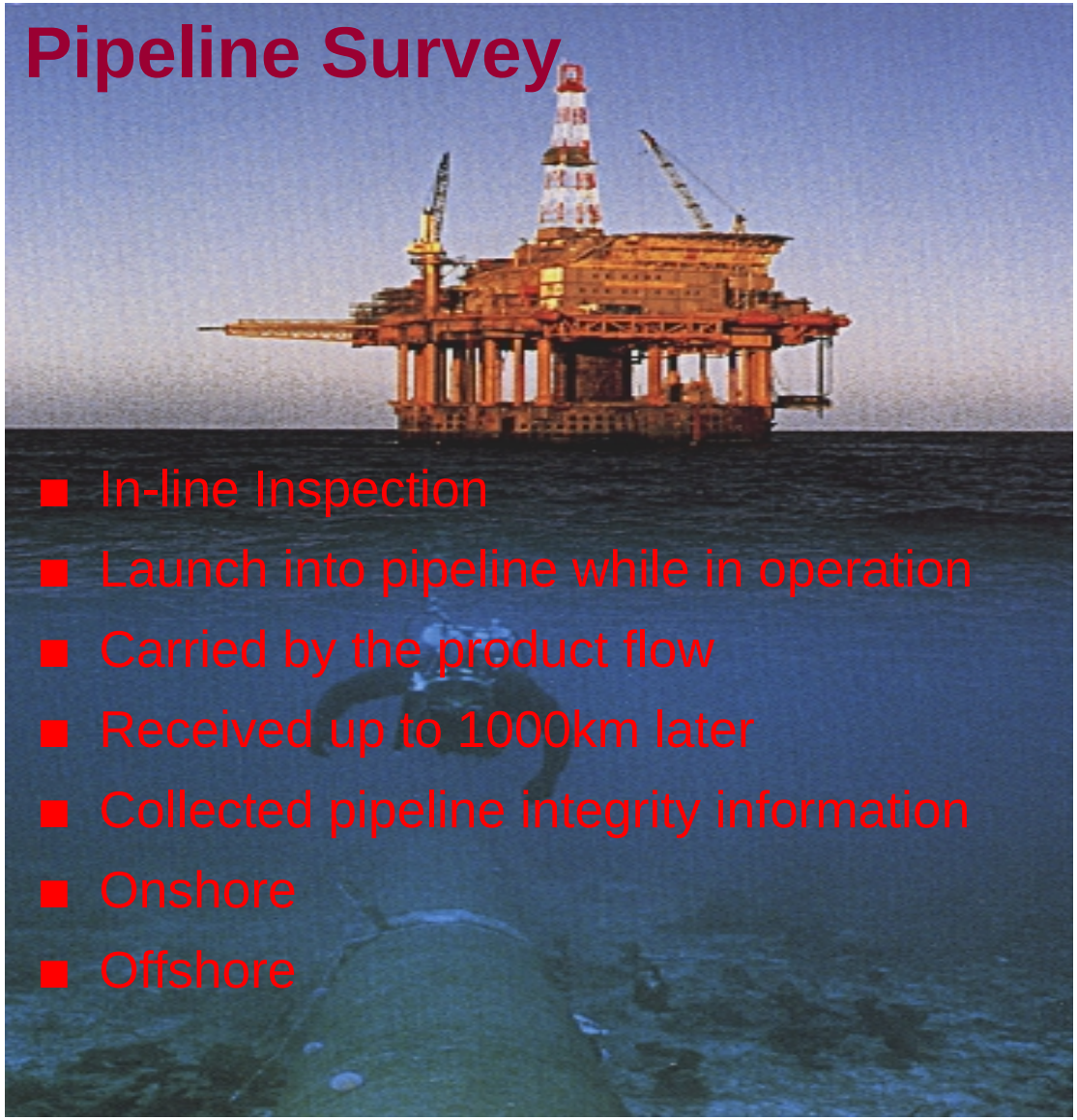


Presentation Outline

- Introduction
- Background
- Approach
- Simulation & Results
- Lessons Learned
- Conclusion

ADAMS

Pipeline Survey



- In-line Inspection
- Launch into pipeline while in operation
- Carried by the product flow
- Received up to 1000km later
- Collected pipeline integrity information
- Onshore
- Offshore

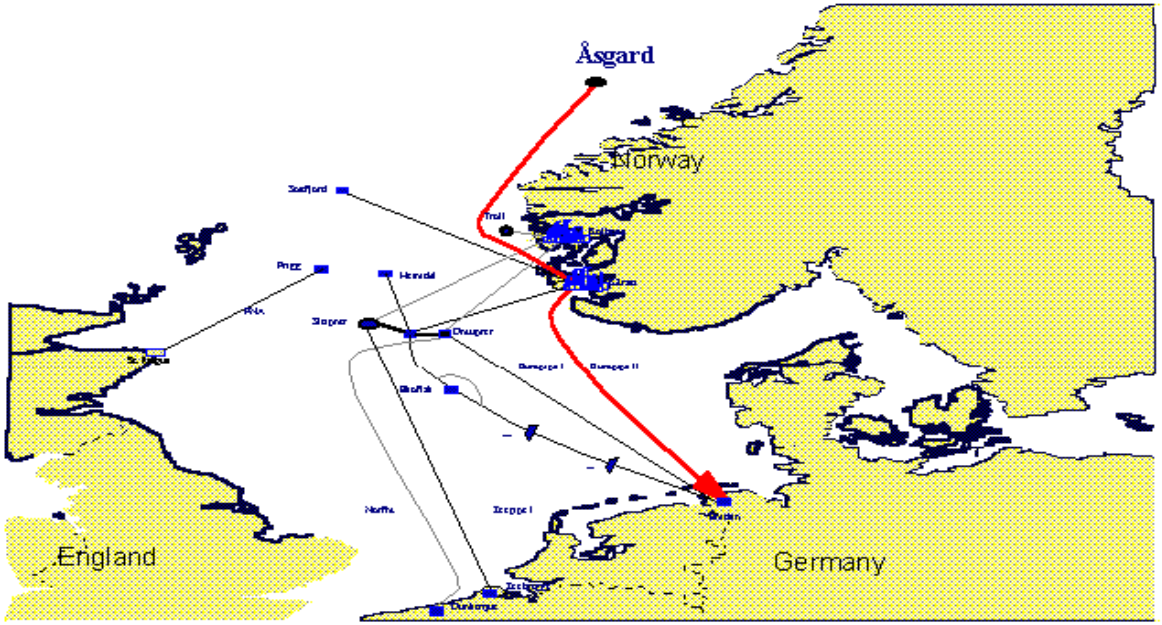
Mechanical Dynamics

North Sea Pipeline System

Åsgard field location

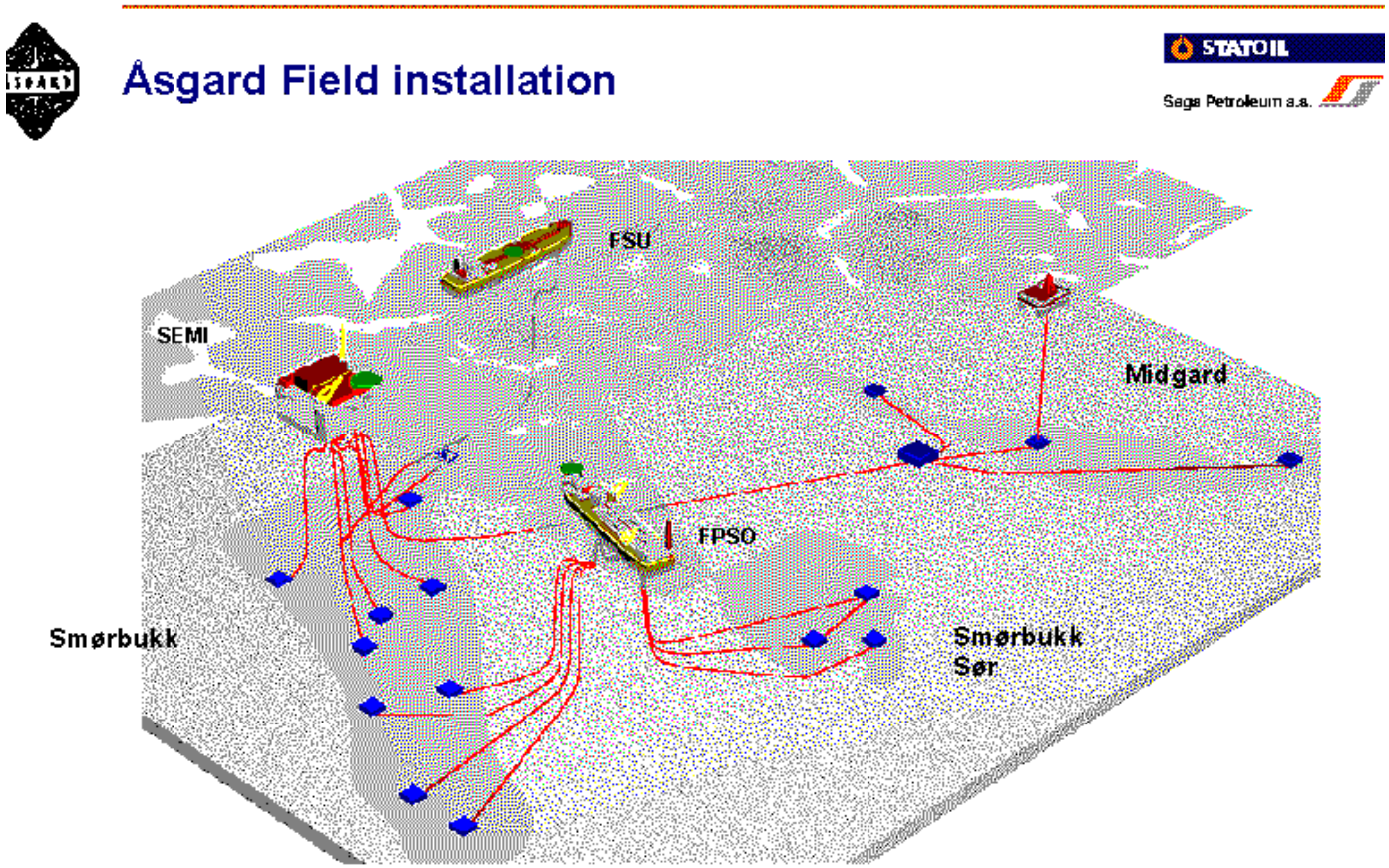
STATOIL

Saga Petroleum a.s.



Mechanical Dynamics

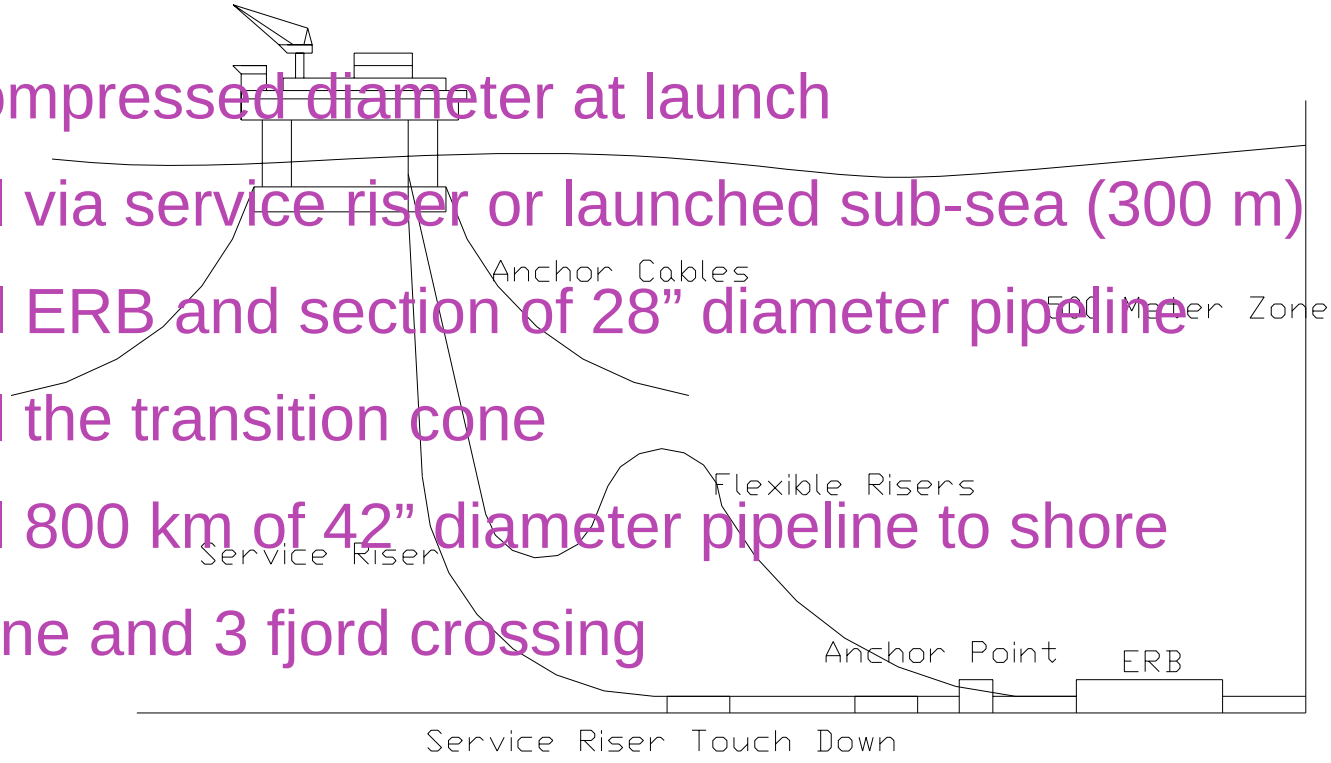
Floating Production Facility



Mechanical Dynamics

The challenge

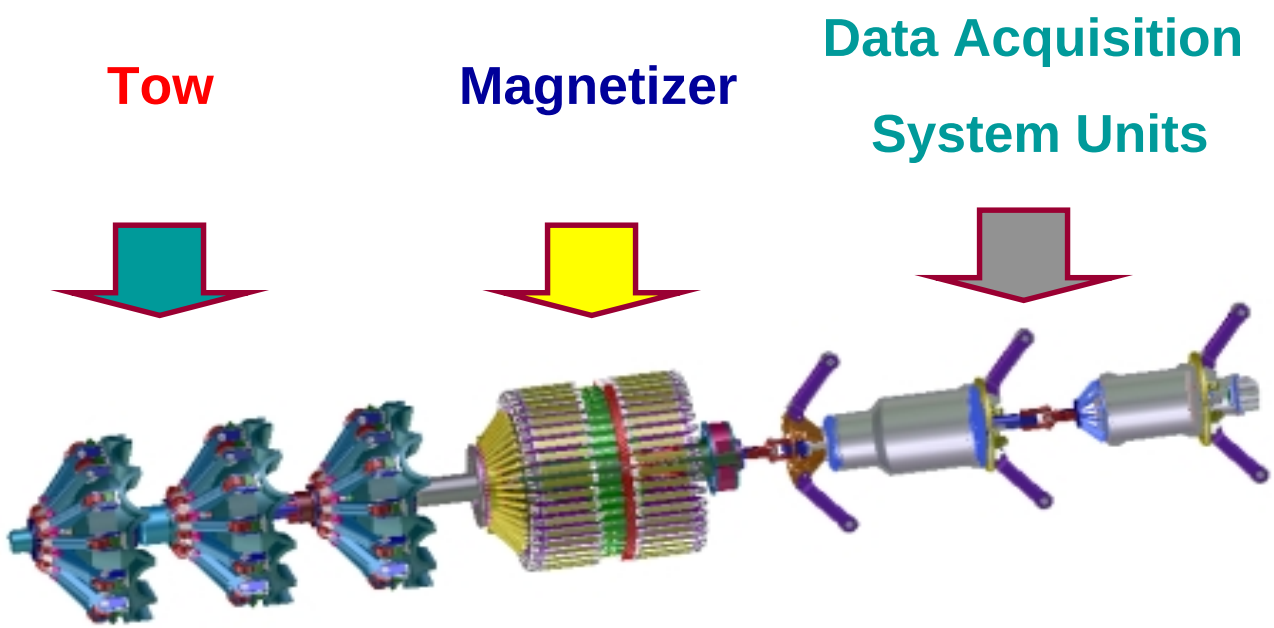
- 28” compressed diameter at launch
- Travel via service riser or launched sub-sea (300 m)
- Travel ERB and section of 28” diameter pipeline
- Travel the transition cone
- Travel 800 km of 42” diameter pipeline to shore
- Landline and 3 fjord crossing



Approach

Tool Description

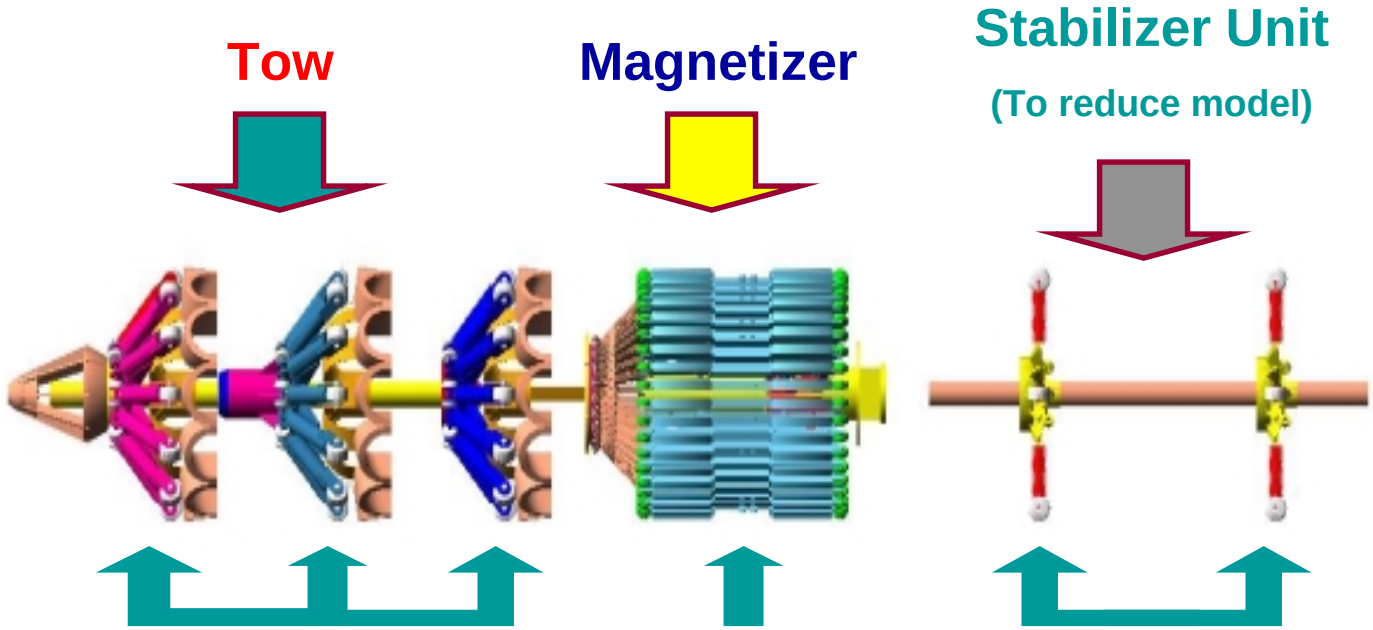
- The tool includes major sub-systems connected by links



Approach

Model Description

- The model of the tool included the tow and magnetizer sections, and a simplified stabilizer section, connected by links and force elements



Tow	Magnetizer	Stabilizer Unit
36 tow arms	42 four-bar linkages	8 stabilizer arms
54 wheels	84 wheels	8 wheels
36 cup elements		

Mechanical Dynamics

Approach

- Model Description
  - Tow Section: The tow section provides the propulsion directly from the pipeline product flow. The following components were modeled:

18 Front Wheels

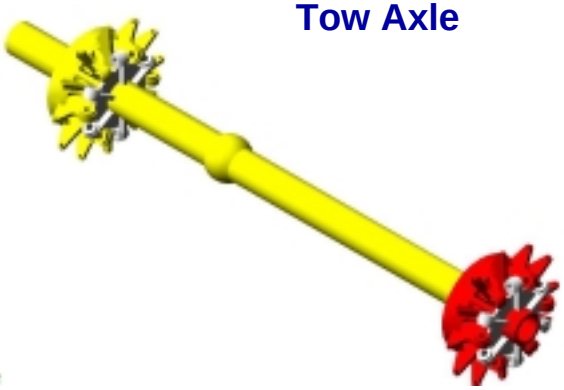
36 Tow Arms

36 Main Wheels

36 Cup elements

Bumper Nose

Tow Axle



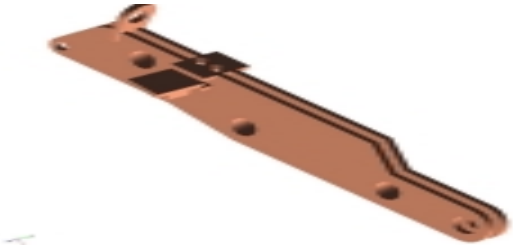
Float Axle

Mechanical Dynamics

Approach

- Model Description
  - Magnetizer Section: The magnetizer section generates the magnetic field used for the pipeline inspection. This field generates very high forces between the linkages and the pipe. The model includes:

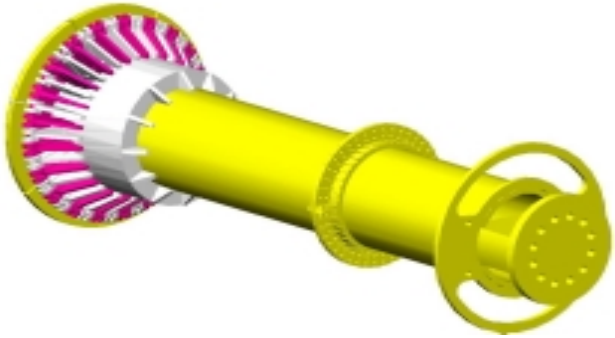
42 Front Links



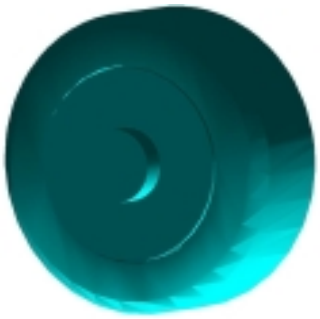
42 Magnetizer Bars

42 Rear Links

Magnetizer Axle



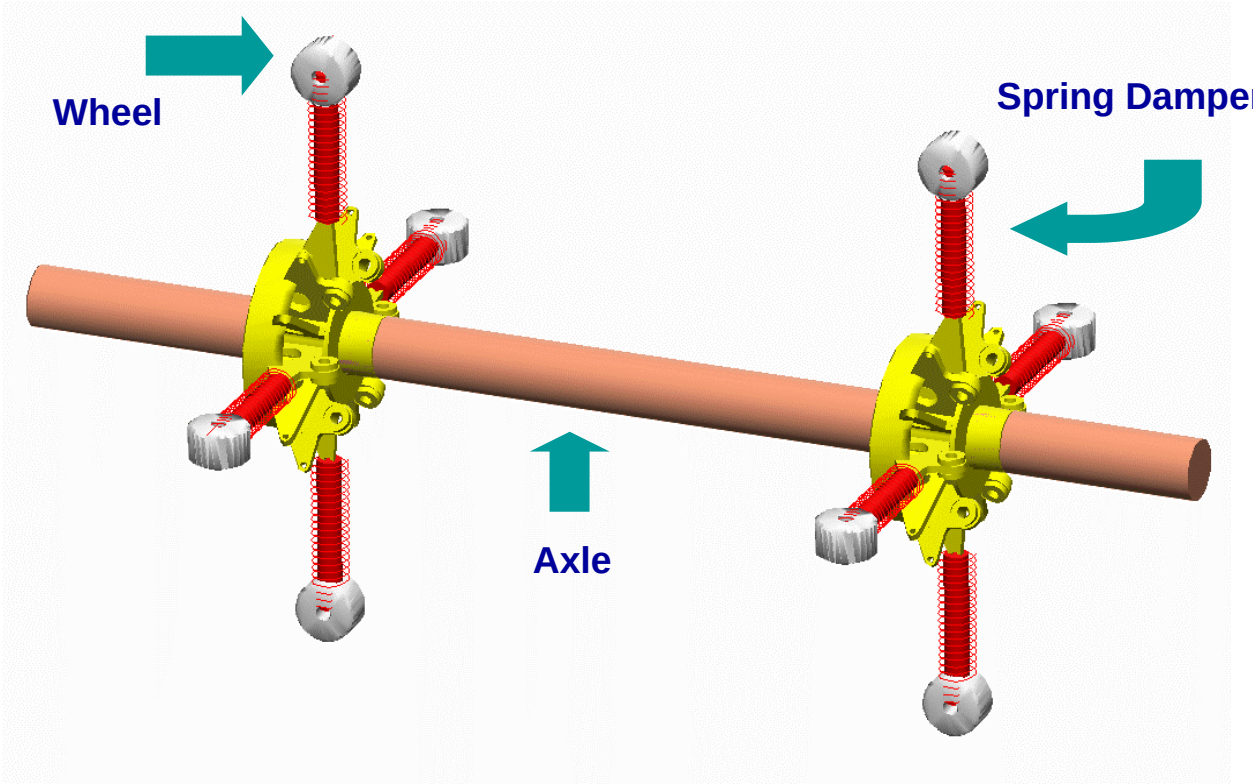
84 Wheels



Mechanical Dynamics

Approach

- Model Description
  - Stabilizer Section: A stabilizer section replicated the test configuration and stabilized the magnetizer. A simplified model was used which includes:



Approach

- Import 3D CAD Model

Tool geometry from Solid Designer → ADAMS/View → A/View macros to duplicate all repeated parts

- **The A/View macros created all repeated parts, joints, forces, and motions for the model.**

Mechanical Dynamics

Approach

- Define Joints
  - Revolute joints - wheels to arms, wheels to magnetizer links, arms to axle, link to axle.
  - Spherical joints - floating section to tow axle, front magnetizer links to magnetizer bars, cups to arms.
  - Hooke joints - magnetizer bars to rear magnetizer links.
  - Orientation joint primitives - cup to tow axle.
  - In-line joint primitive - stabilizer axle to magnetizer axle.
  - Translational Joints - stabilizer arms to stabilizer axle, tow axle to ground

Approach

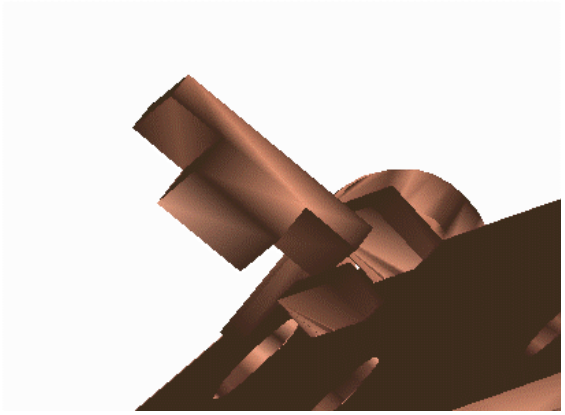
- Develop Contact Model

Types of contact forces used in the model include:

- Arm stops - vforce
- Synchronizers - vtorque
- Wheels to pipeline - gforce
- Magnetizer brush to pipeline - gforce
- Bumper nose to pipeline - gforce
- Float section to tow axle - vforce

Approach

- Develop Contact Model
  - Tow arm synchronizer forces - bi-stop impact forces (vtorque)
  - Magnetizer link synchronizer forces - bi-stop impact forces (vtorque)

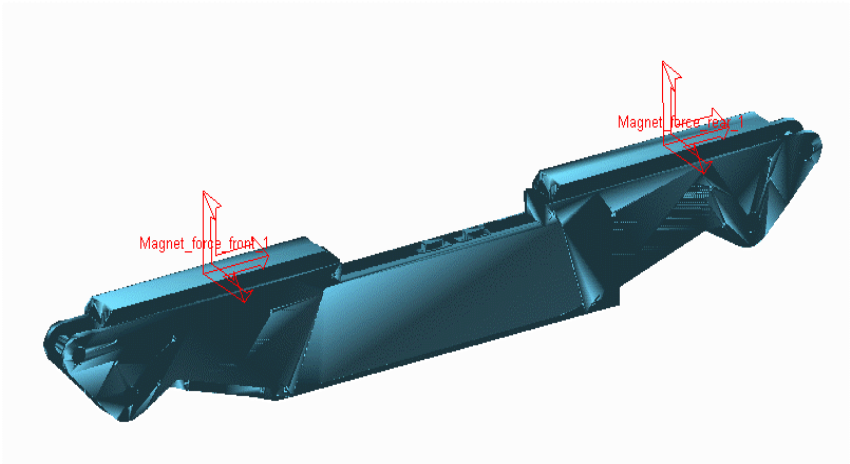


Magnetizer Links

Tow Arms

Approach

- Define Force Elements
  - Bushings - bumper nose to tow axle, float section to tow axle
  - Linear spring dampers - tow arms, magnetizer links, and stabilizer arms
  - Magnetizer flux forces - constant force vectors (vforce)

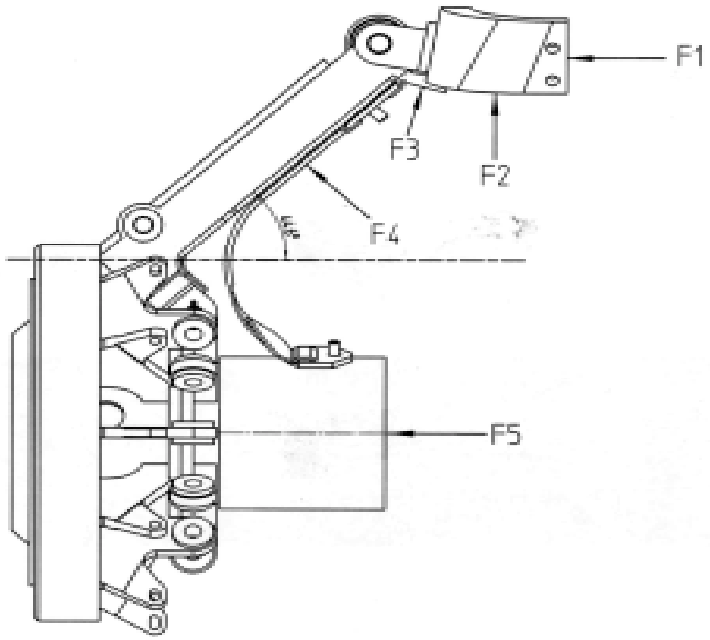


Magnetizer flux forces

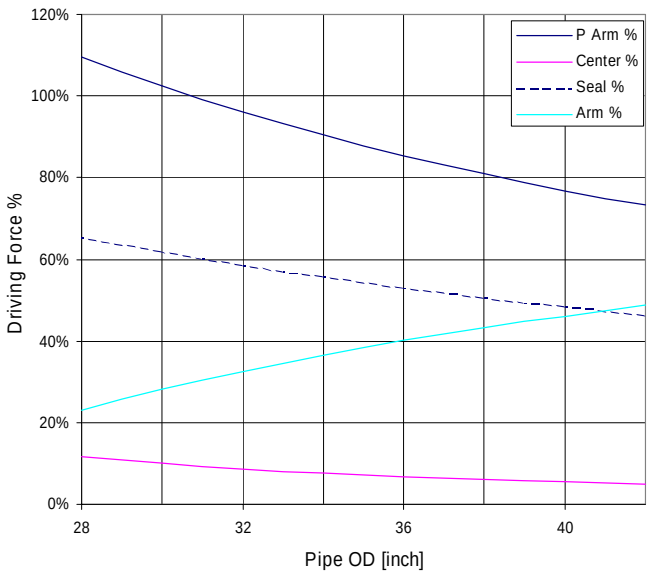
Mechanical Dynamics

Approach

- Define Force Elements
  - Tow driving forces - empirical data (vforce)



Driving force orientation

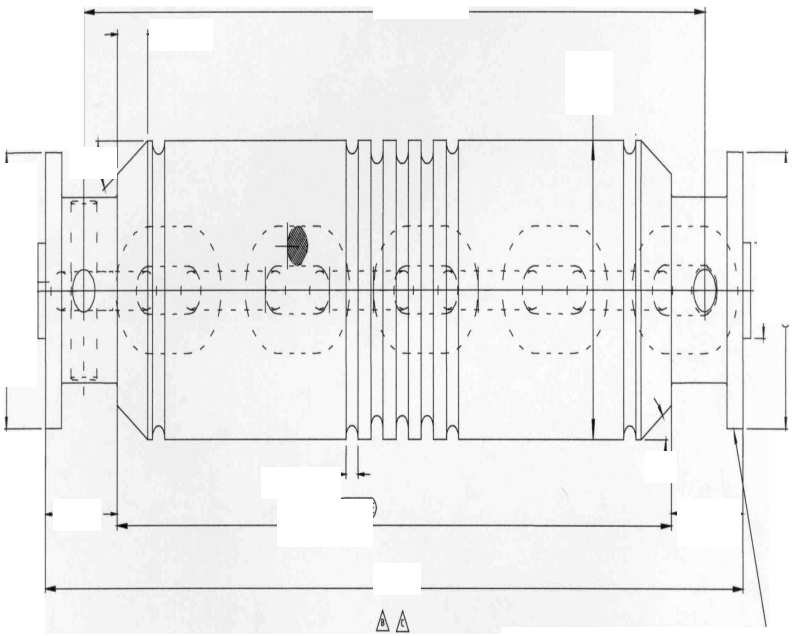


Testing data

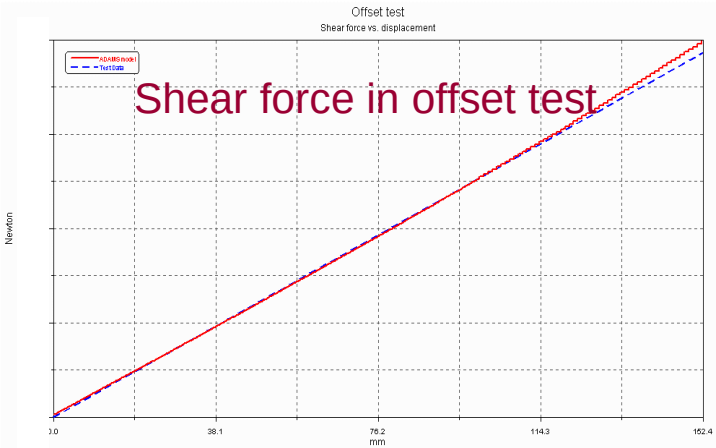
Mechanical Dynamics

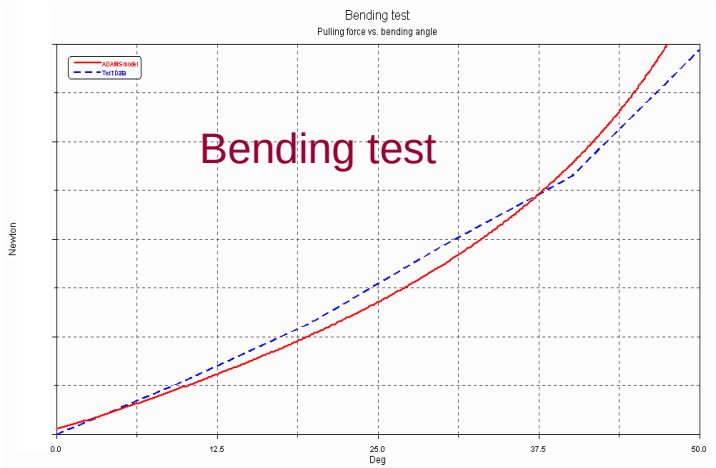
Approach

- Define Force Elements
  - Flexible tow link - Beam elements, correlated with test data.



Flexible tow link





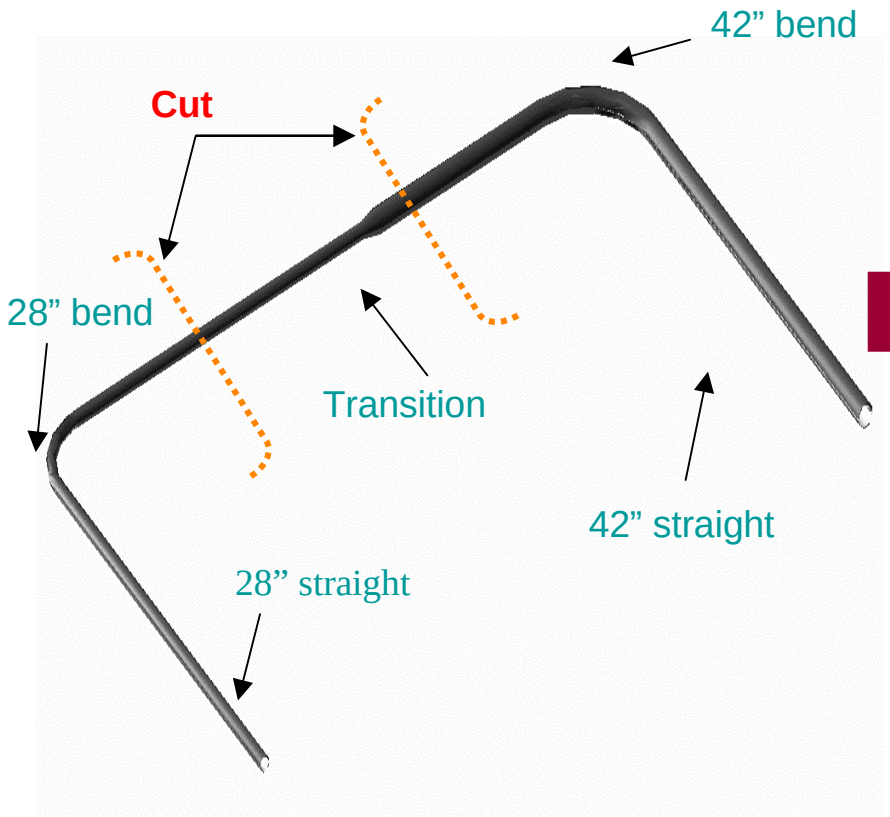
Mechanical Dynamics

Model

- Model Statistics
  - Number of moving parts = 389
  - Number of DOF = 316
  - Number of contact forces = 865
  - Number of force elements = 290
  - Overall mass = 4~5 tons
- CPU Time Statistics
  - Full model in transition = 34 hours (Pentium II, 450 MHz)
  - Full Model in straight weld pipe = 44 hours (SGI Indigo2, 195MHz)
  - Full model in bent pipe = > 200 hours (Pentium II, 450 MHz)

Model

- Pipeline test circuit features



The model was tested in three separated sections:

42” bend + straight + weld

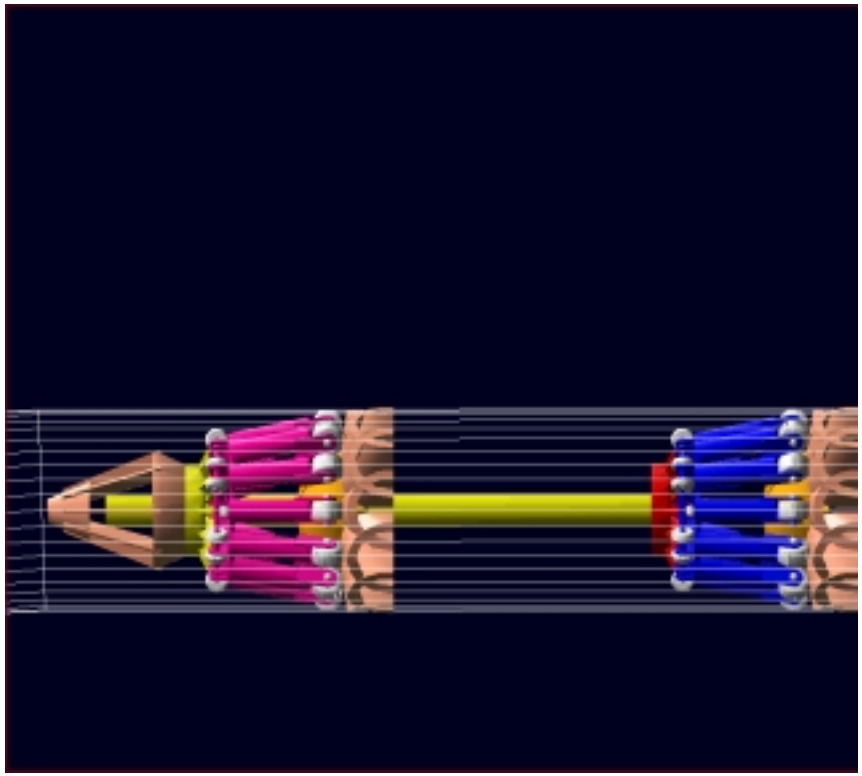
Transition

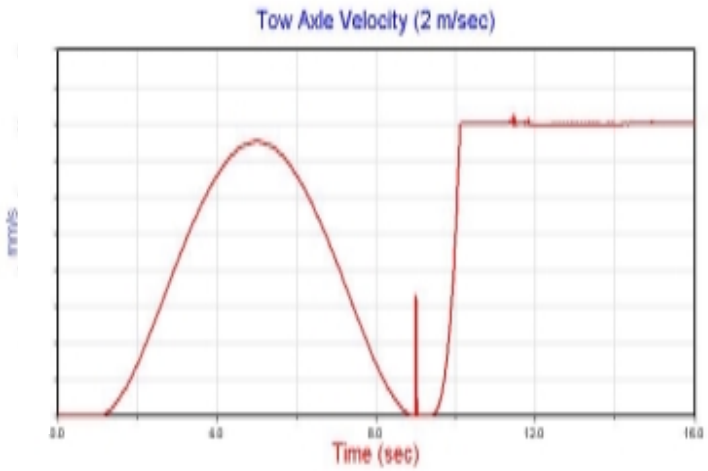
28” bend + straight

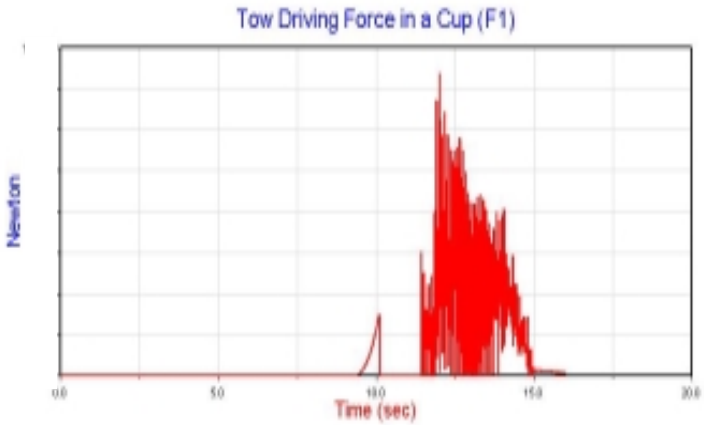
Mechanical Dynamics

Simulation & Results

- Test simulations with tow section only
  - 28” bend



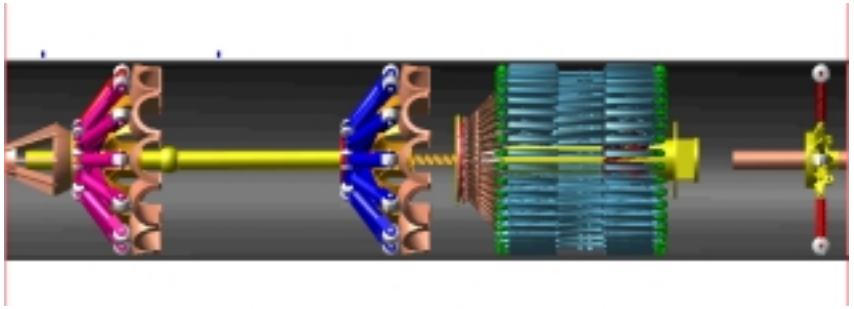




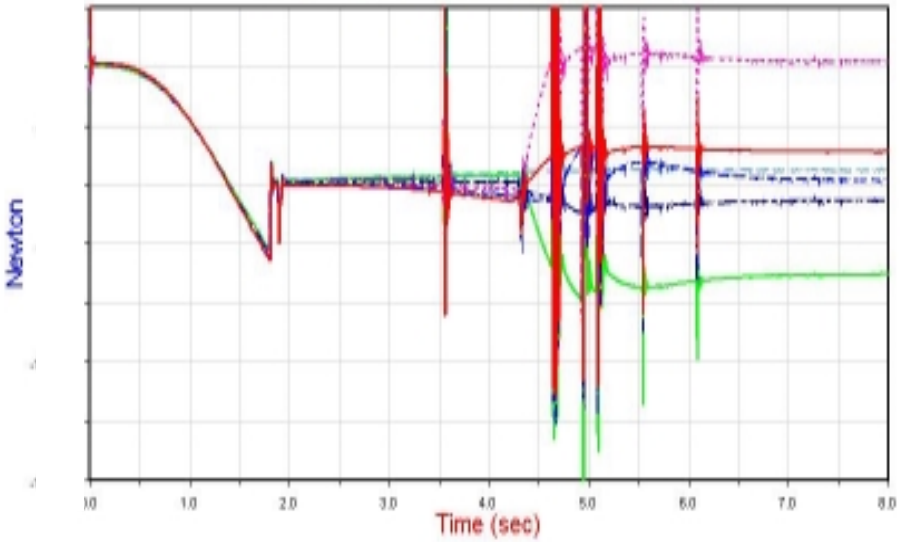
Mechanical Dynamics

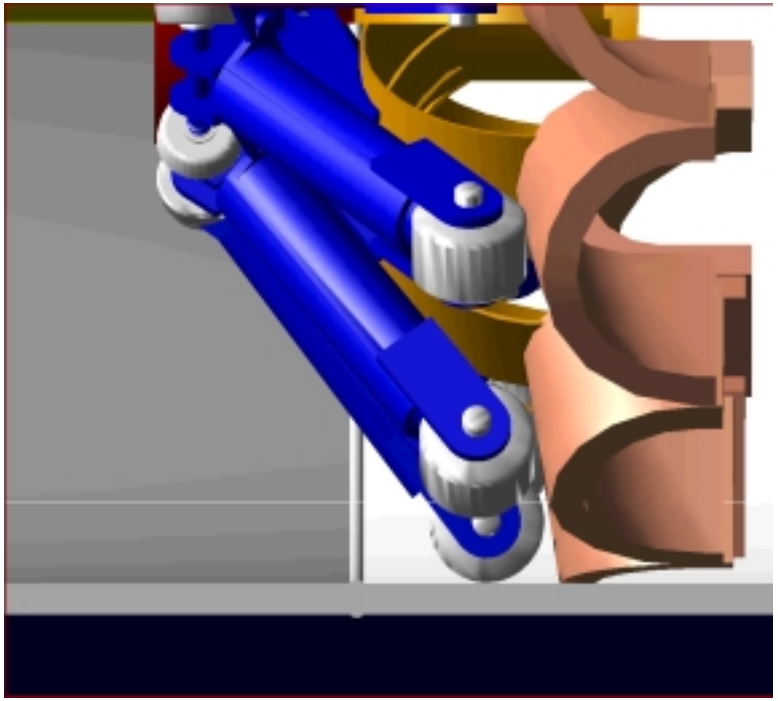
Simulation & Results

- Full model with 42” straight weld pipe



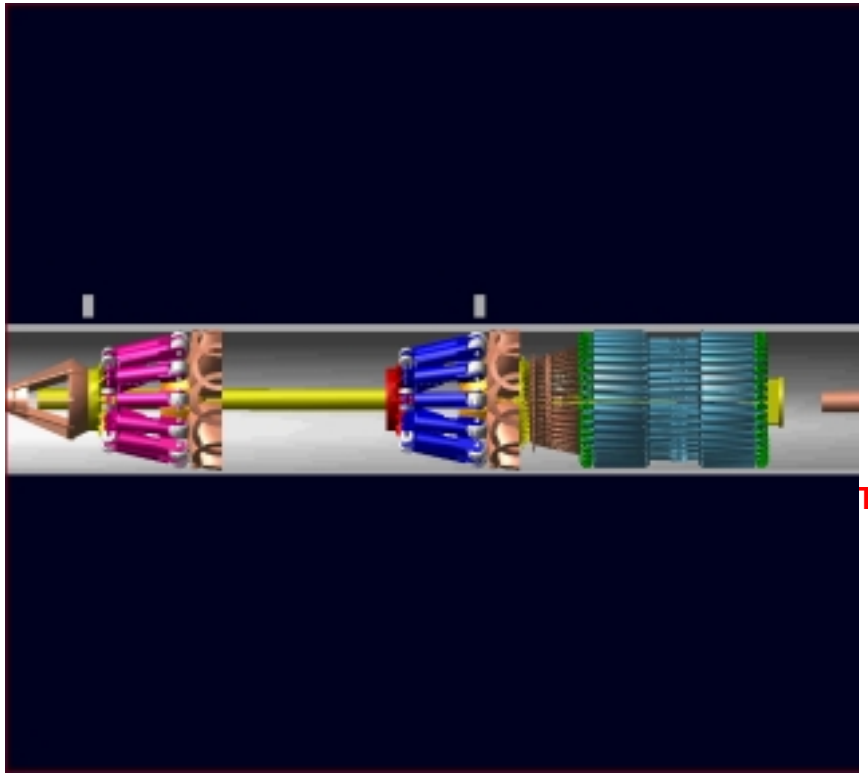
Front Tow Arm Wheel to Pipeline Contact Force





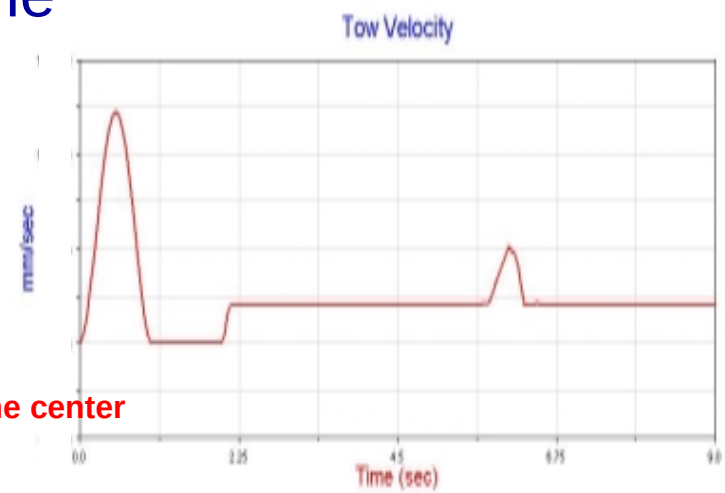
Simulation & Results

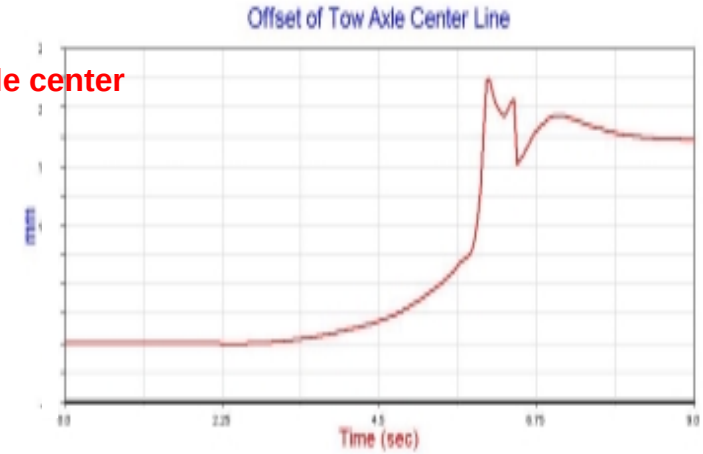
- Full model with transition pipeline



Pipeline center

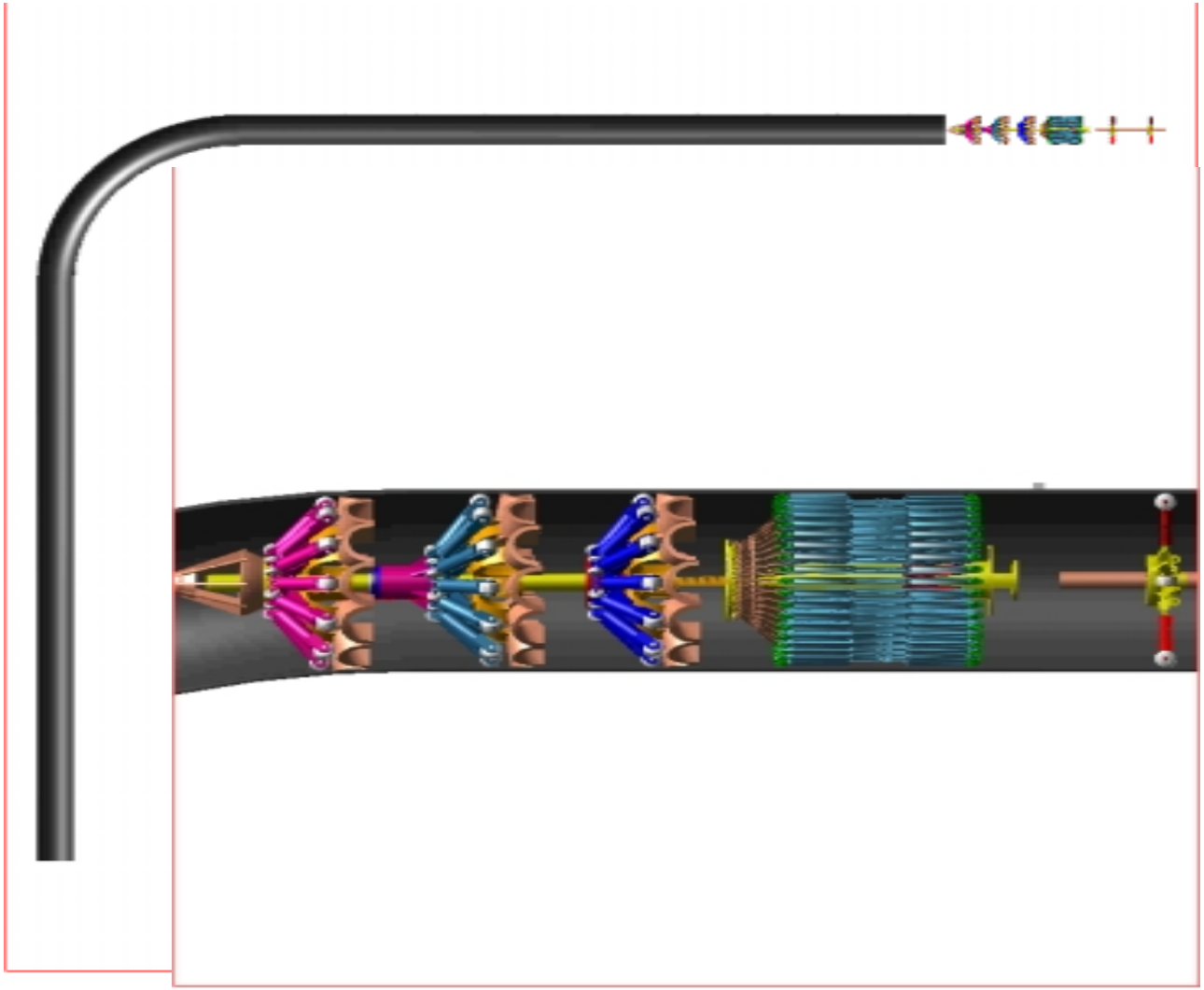
Tow axle center





Simulation & Results

- Full model with 42” bent pipe



Lessons Learned

- Start small & refine model
  - Test each modeling element in a single arm or linkage, e.g.,
    - wheel contact force, tow arm spring, tow arm synchronizer…
  - Test each tool section separately with all pipe geometry, e.g.,
    - tow section, magnetizer, and stabilizer
  - Test the full model with imposed motions and constraints
    - static > transient > dynamics
  - Test the full model starting with simple pipe geometry to complex pipe geometry, i.e.,
    - straight > transition > bend

Lessons Learned

- Convergence problems: artifact versus reality
  - ADAMS/Solver sometimes experienced difficulty with the large number of contact forces and DOF
  - Model convergence problems occurred when highly concentrated forces were generated by the full model running into the bend section
  - The magnetizer linkage was broken in the physical prototype when the tool was sent into the bend section

Lessons Learned

- Accurate test data required for model input
  - Test data was used to characterize:
    - tow driving forces
    - tow link bend and shear test
    - magnetizer flux
    - wheel contact stiffness and frictions
    - magnetizer brush force contact stiffness and frictions
  - Model components were individually tested to ensure correlation to test data

Summary & Conclusion

- Using ADAMS to create a virtual prototype of the pipeline inspection tool was an innovative approach not previously attempted in the oil industry
- ADAMS provided comprehensive data which contributed to the understanding of system behavior prior to completion of hardware prototype and testing.