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Equations of State in Fighter Aircraft Oleo-pneumatic Shock Absorber Modelling

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Introduction

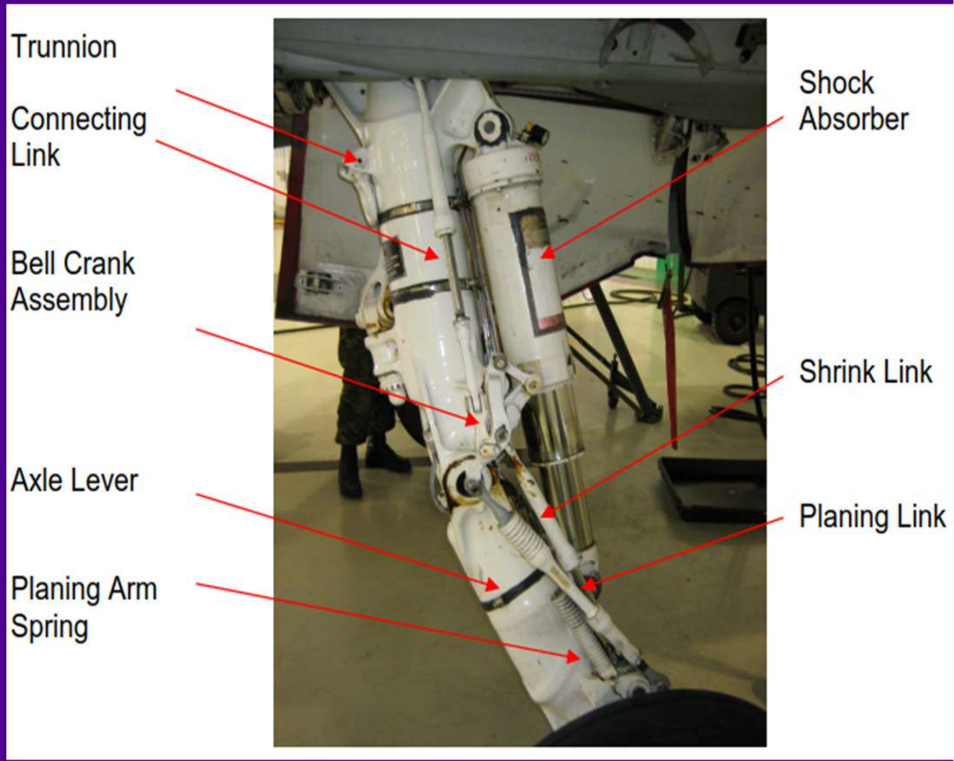
Motivation: a planing mechanism assembly failure (PMA)

An axle lock link becomes unlocked

- Allows the main wheel to deplane
- Lost in directional control
- The failure has occurred globally

A specific cause has not been identified

- Tire pressure, **shock absober servicing**, link buckling, among others



Grandmont, Eric Joseph, "A Study of the CF188 Landing Gear Upgrade. " Master's Thesis, University of Tennessee, 2009. http://trace.tennessee.edu/utk_gradthes/81

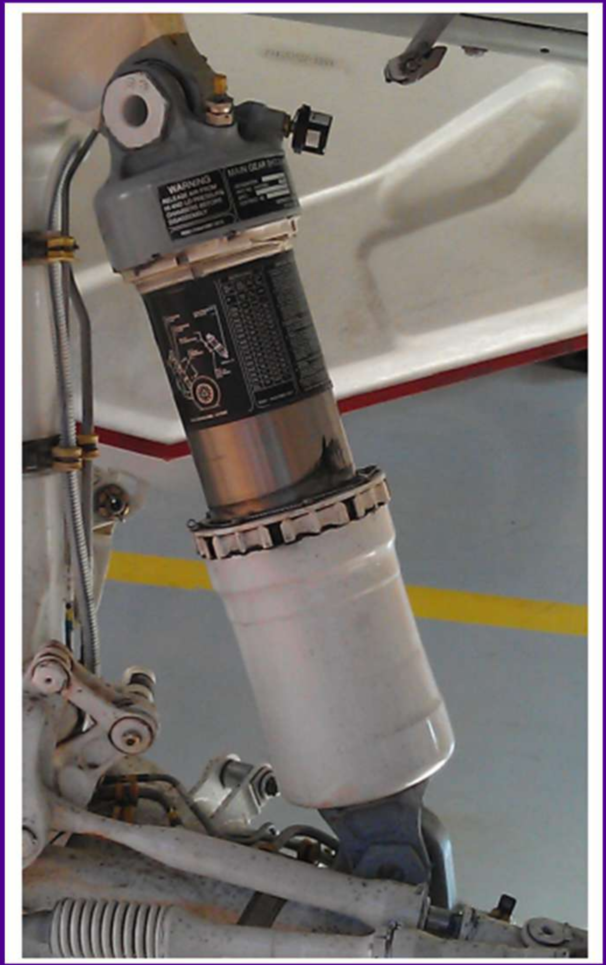
Introduction

Objectives

- Learn new information of the operation of the shock absorber
- Investigate the operation during landing
- Advance condition monitoring methods of the shock absorber

Field testing too expensive and dangerous

→ Modelling and simulation



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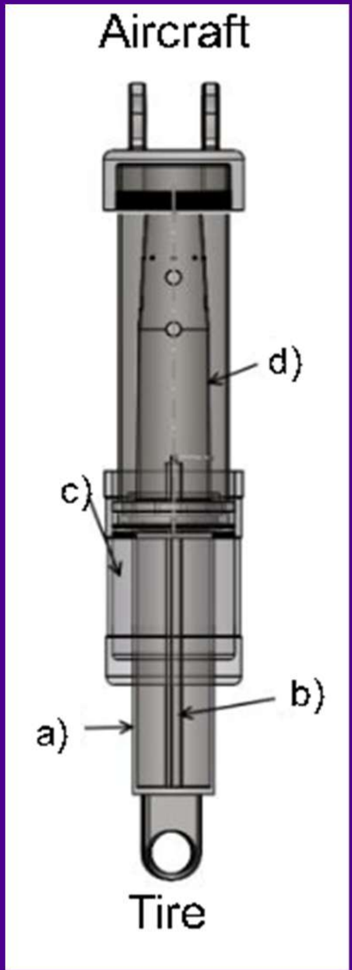
Two Stage Oleo-Pneumatic Shock Absorber



a) Primary piston assembly
- Hydraulic oil

b) Metering pin
- Variable cross-section

c) High pressure chamber
- Nitrogen in high pressure

d) Orifice support
- Low pressure nitrogen and hydraulic oil

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Gas modelling

Different ways to model the gas volumes

- Modelling the gas dynamics
  - The motion of the gas is taken into account
  - Parameters vary across the gas volume

- Modelling the gas using control volumes
  - Mass and heat are exchanged between control volumes
  - The gas dynamics within the control volume are neglected
  - The parameters (temperature, etc.) are averaged across the control volume

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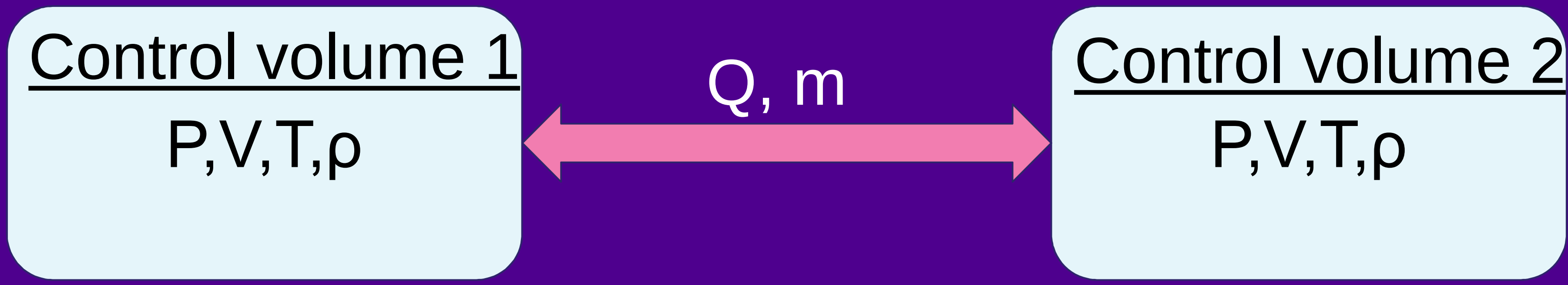
Control volume approach



Two ways to model the thermal behaviour using control volumes

- Polytropic process
  - Gas behaviour is modelled using only one constant
- General internal energy model
  - Gas behaviour is modelled based on the first law of thermodynamics

Polytropic process:

pV^k = Constant, where K = polytropic index

Theoretical values:

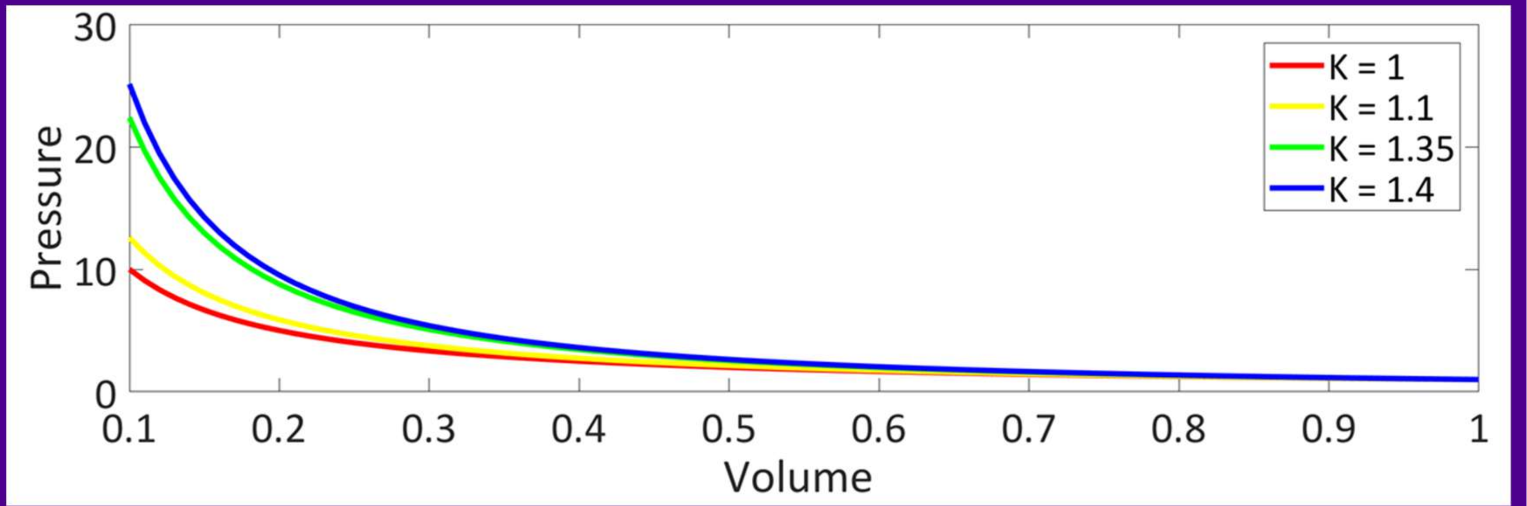
1.0 for quasi-static (slow) compression, isothermal

1.4 fast compression, adiabatic

Real values:

1.35 if the gas and oil are separated

1.1 if they are mixed



General internal energy model

$$\begin{bmatrix} V.\left(\frac{\partial \rho}{\partial p}\right)_T & V.\left(\frac{\partial \rho}{\partial T}\right)_p \\ m.\left(\frac{\partial h}{\partial p}\right)_T - V & m.\left(\frac{\partial h}{\partial T}\right)_p \end{bmatrix} . \begin{bmatrix} \frac{dp}{dt} \\ \frac{dT}{dt} \end{bmatrix} = \begin{bmatrix} \sum \frac{dm_i}{dt} - \rho . \frac{dV}{dt} \\ \sum \frac{dm_i}{dt} . h_i - h . \sum \frac{dm_i}{dt} + \delta Q \end{bmatrix}$$

Starting from the rate of change of mass and internal energy, the above system of equations can be derived

The derivatives of density can be had from the gas equation of state

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Equations of state

Ideal gas law: $PV = mrT$

Van der Waals: $\left(P + \frac{a}{V^2}\right)(V - b) - rT = 0$

Redlich-Kwong-Soave: $\left(P + \frac{a\alpha(T)}{V(V+b)}\right)(V - b) - rT = 0$

Peng-Robinson: $\left(P + \frac{a\alpha(T)}{V^2+2bV-b^2}\right)(V - b) - rT = 0$

a, b are constants and α thermal dependent factor,

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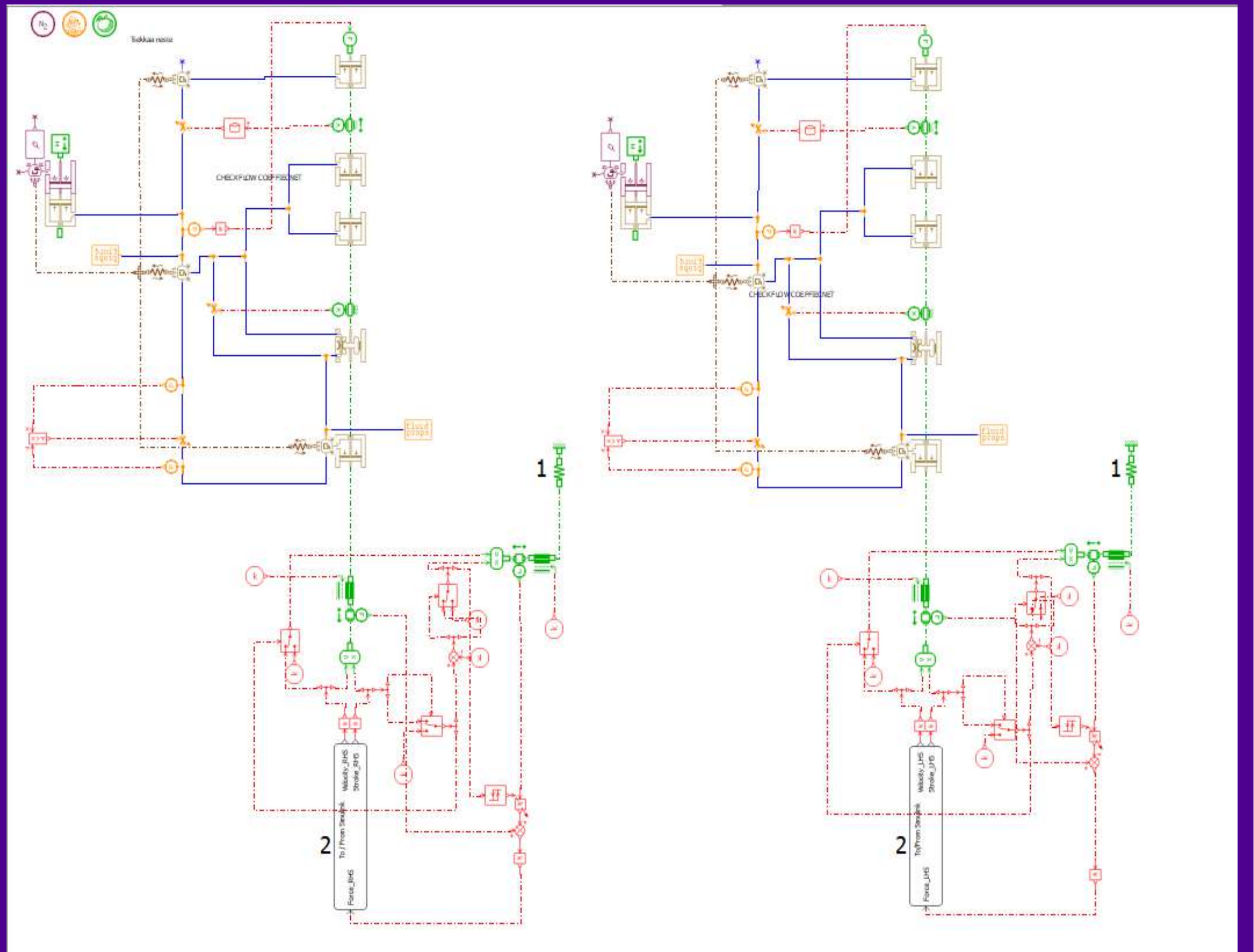
Shock Absorber Model

- Created using a commercial multi-domain simulation software LMS Imagine.LAB Amesim
- Governing equations generated from the Bond graph of the system
- The model has the effects of damping, gas spring and friction incorporated



Validation measurements

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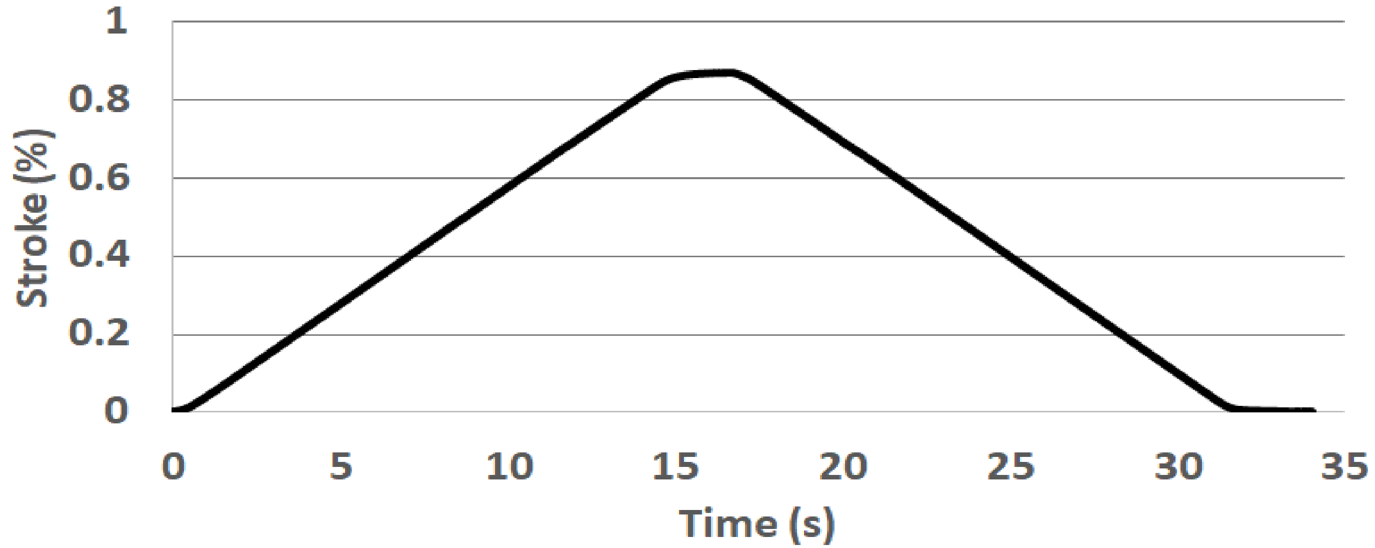
The validation of the model was done using two different cases

- A quasi-static compression
- Dynamical compression
- Using polytropic process requires the change of the polytropic index

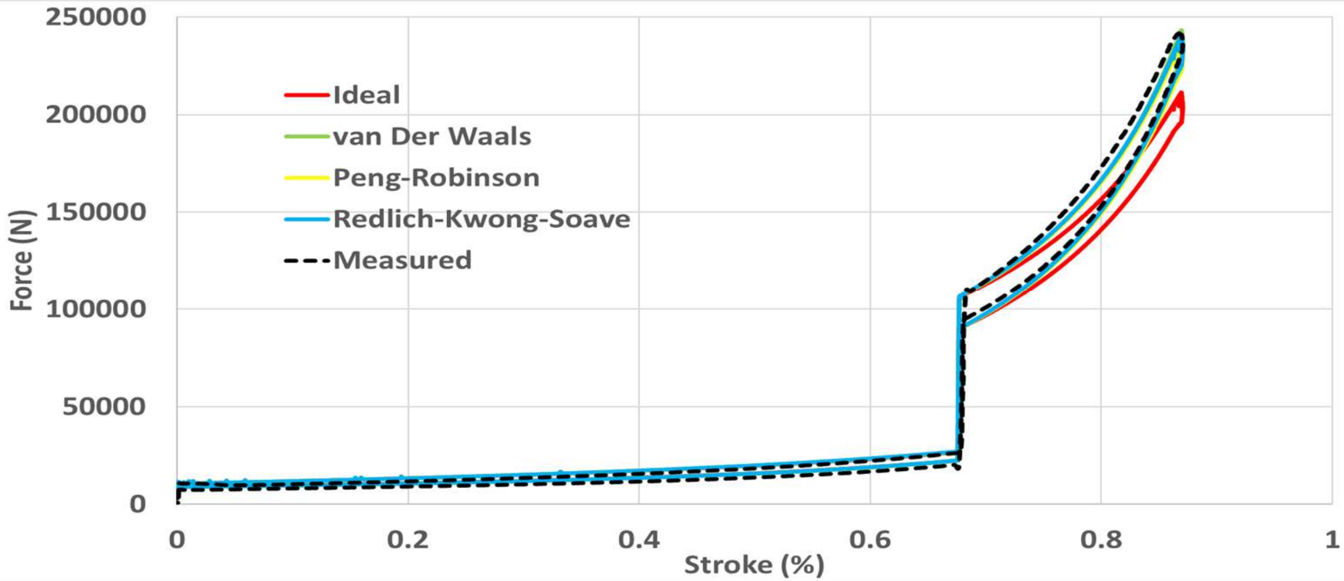
Quasi-static compression

Input:
The shock absorber is compressed slowly



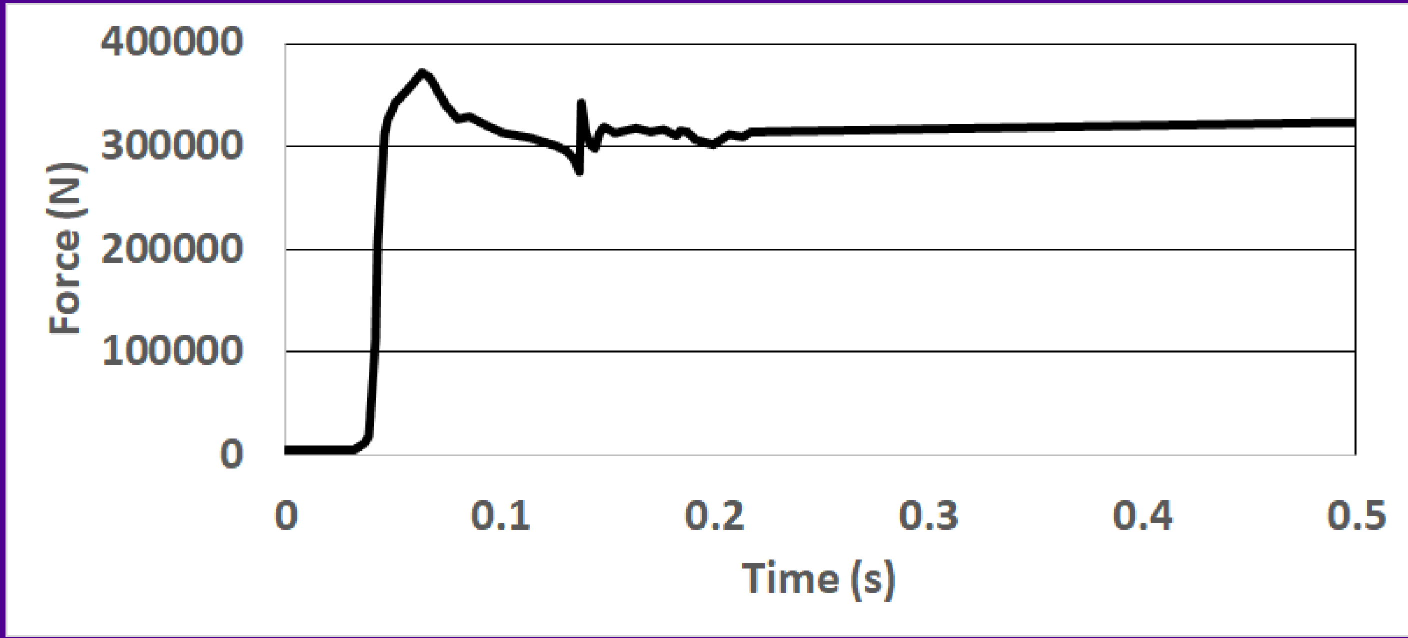
Output (Force vs Stroke %):

- Ideal gas law performs poorly
- Small difference with other EOS



Dynamic compression

Input:
The shock absorber is compressed using force as an input



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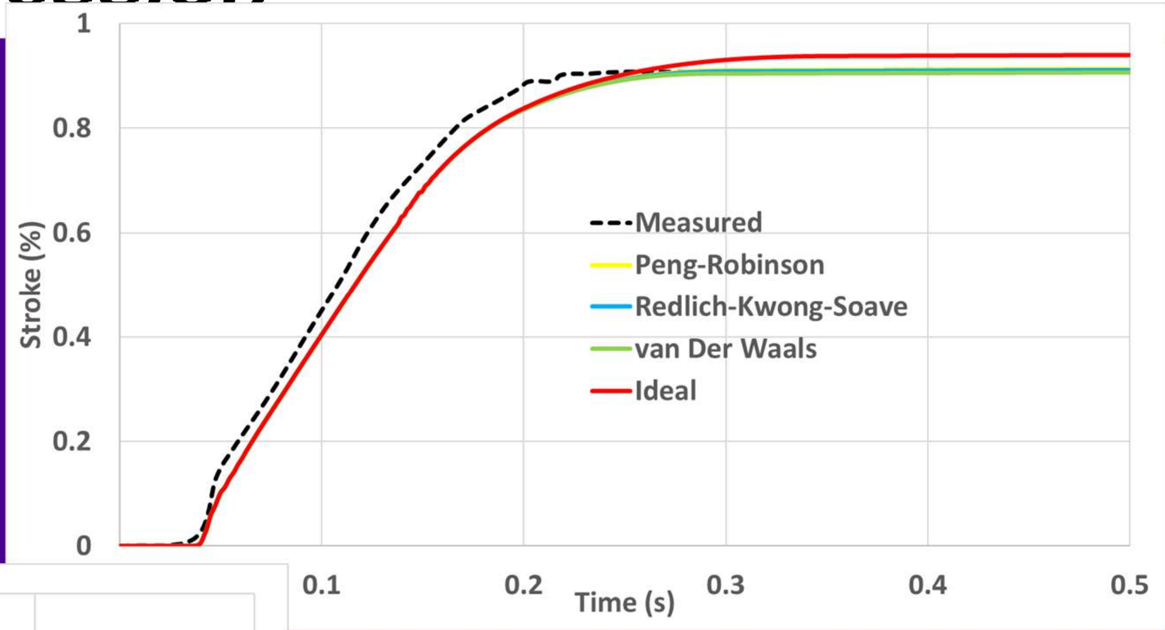
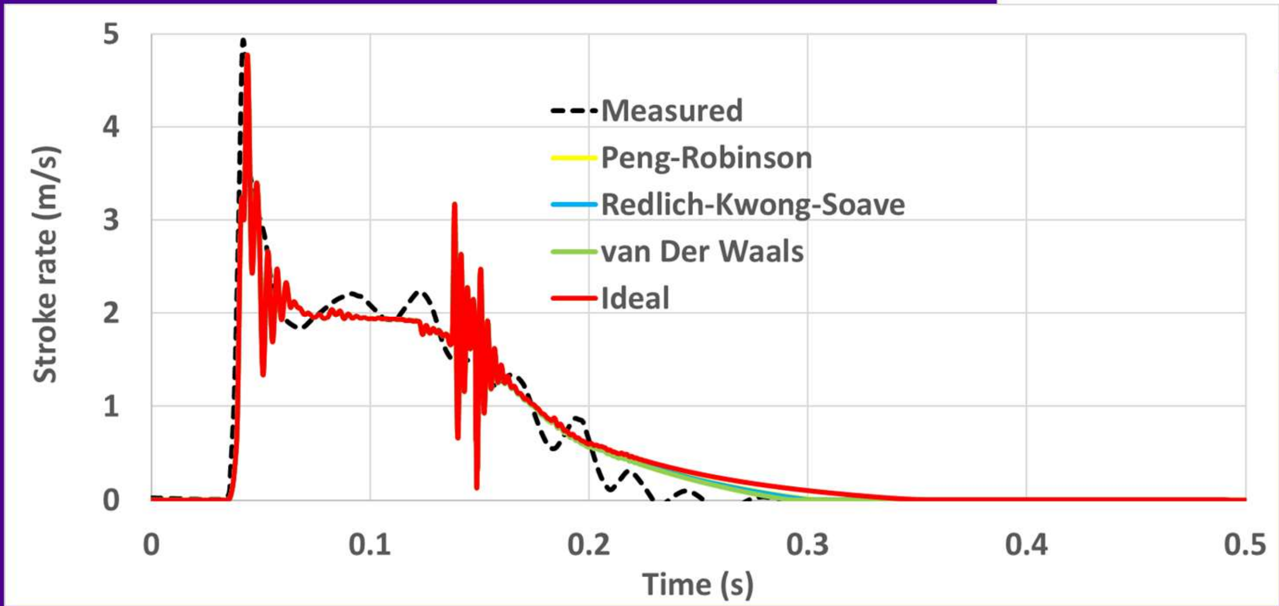
Dynamic compression

The ideal gas law predicts too loose spring





Also the the shock absorber reaches zero velocity later than the other EOS

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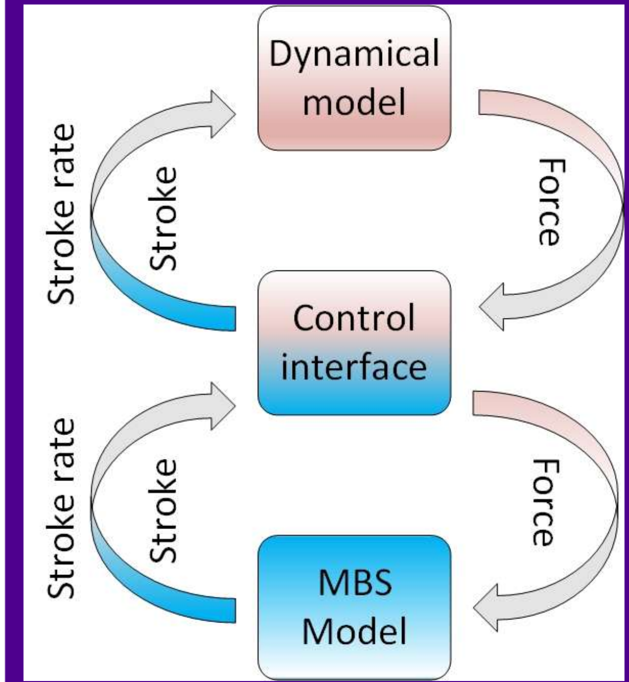
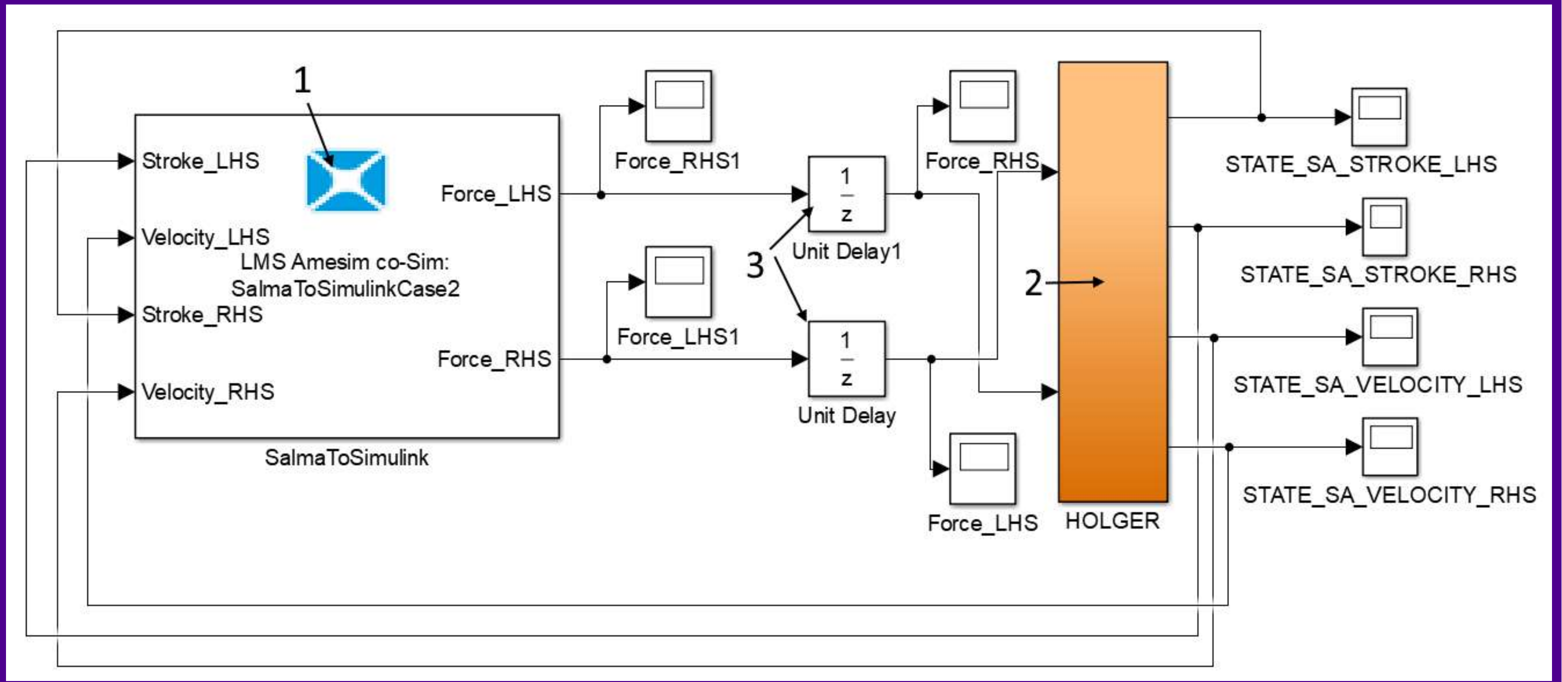
Discussion

- Overall the ideal gas law predicts poor results and should not be used when modelling naval fighter aircraft
- Might be fine with conventional aircraft, as the pressures inside the shock absorber are lower
- It is suggested that other EOS are used, preferably Peng-Robinson as it should be the most accurate according to literature

Coupled simulation





- The shock absorber model was connected to a MBS model using a Matlab interface
- A rigid model of the landing gear with real aircraft mass
- Solves the kinematic and kinetic equations and lift, gravity, tire compression, etc.

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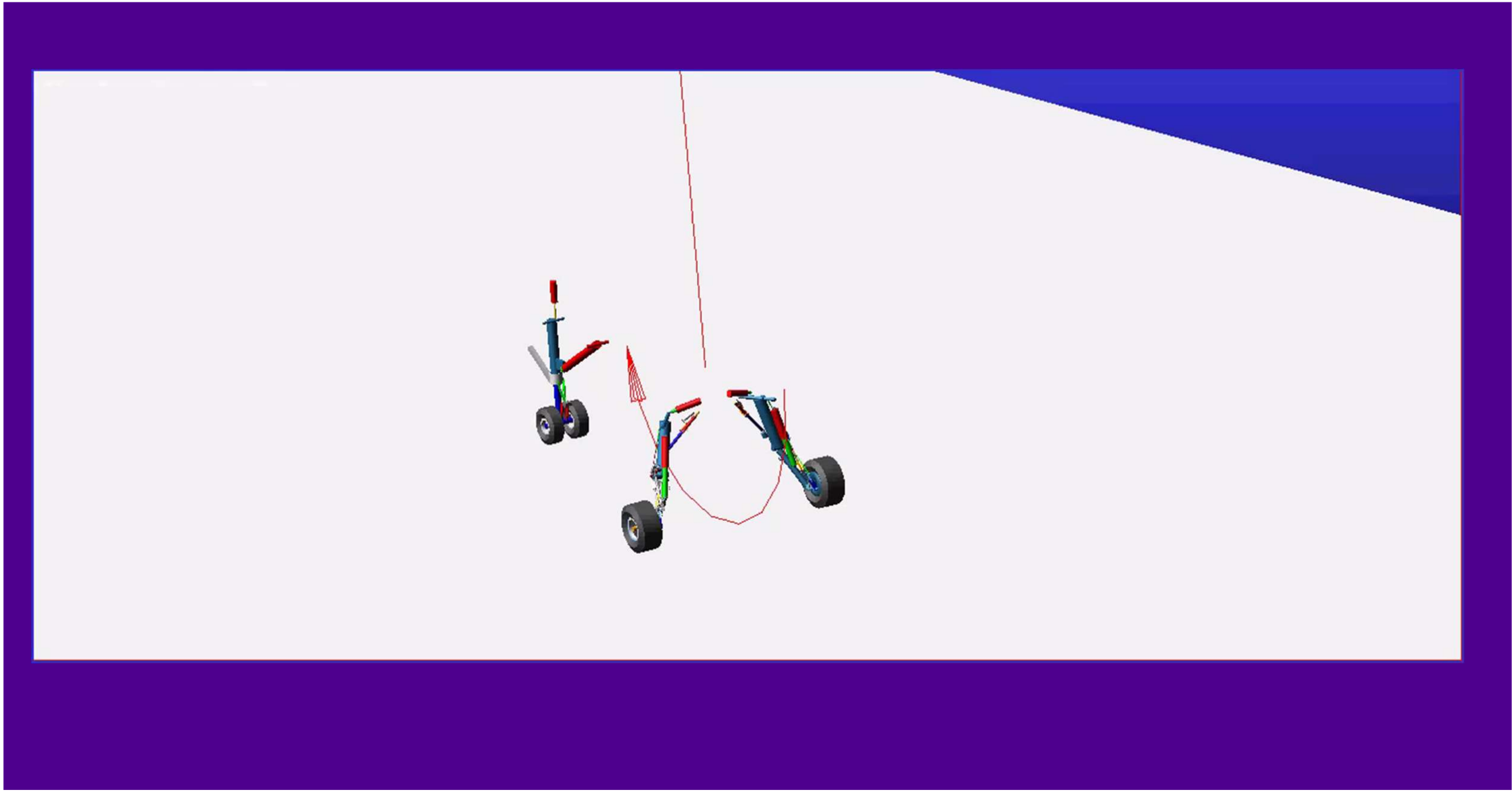
Coupled simulation



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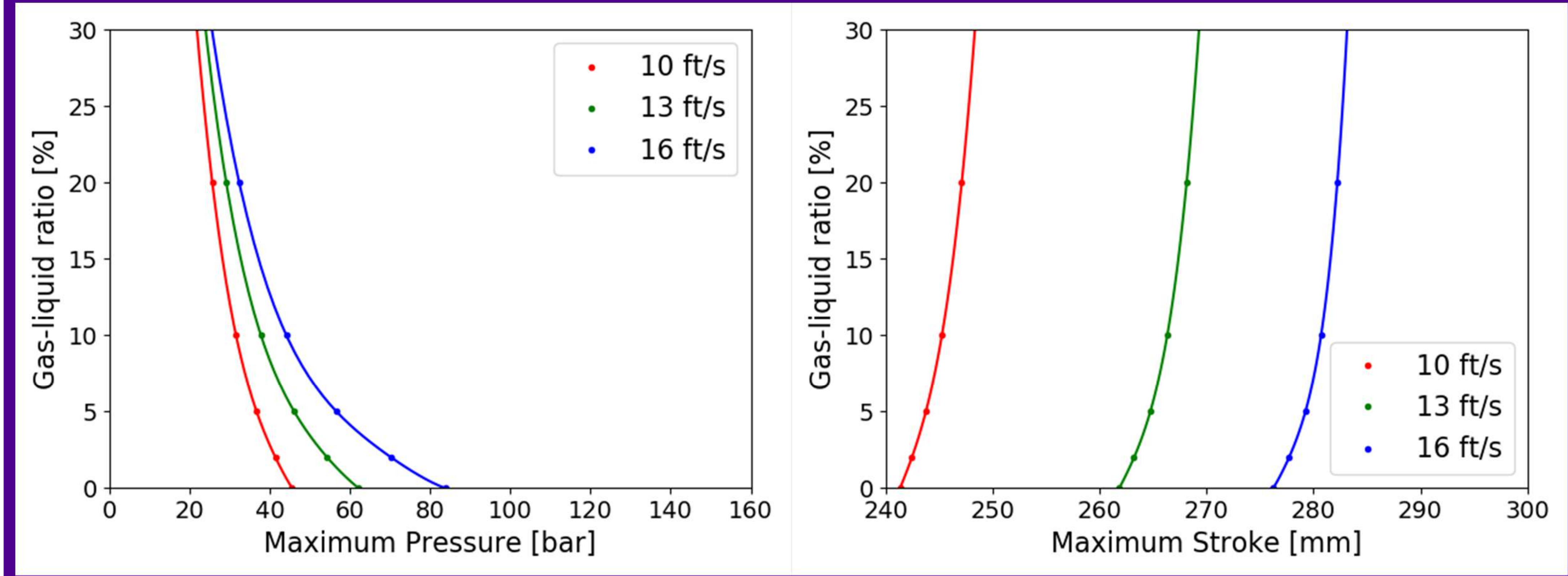
Gas-liquid ratio



Distorting the ratio of gas and liquid affects the pressure and the maximum stroke during landing

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Thank you for your time!

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