Dynamic Modeling of Low Temperature Stirling Engines

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BACKGROUND

The University of Alberta's DTECL (Dynamic Thermal Energy Conversion Laboratory) has historically limited its computer simulation and design to 2nd order models of Stirling engines. These models contain much of the needed physics required but perform poorly when losses interact with each other and provide no understanding of mechanism dynamics. The inaccuracy caused by this is made more apparent when running the Stirling engine with a low maximum temperature ~ 100 ℃. Examples of this effect are shown in Figure 1.

AIMS AND OBJECTIVES

TRANSIENT MODELLING
A 3rd order model will be capable of simulating the natural dynamics on an engine

TRUE LOSS INTERACTIONS
Losses will be coupled, allowing prediction of the instantaneous engine speed which is the product of instantaneous pressures, friction and component inertia effects.

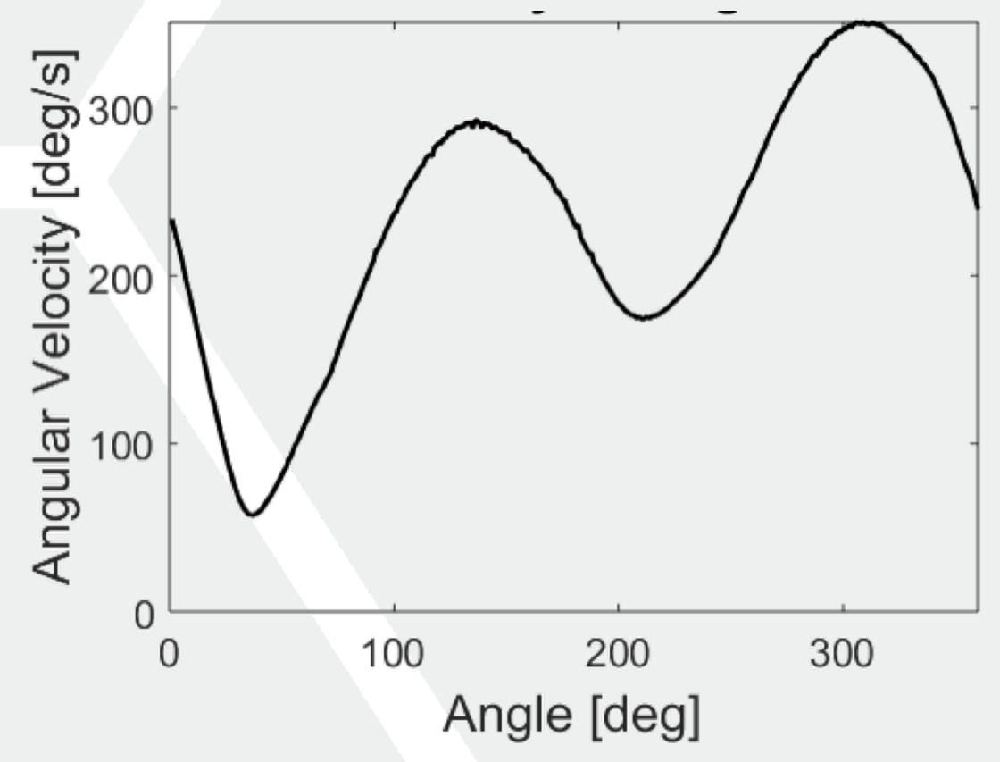


Figure 2: Real engine velocity fluctuations

1st Order Modelling

1st order modelling is primarily guided by generalized geometry, non-dimensional numbers and ideal cycles.

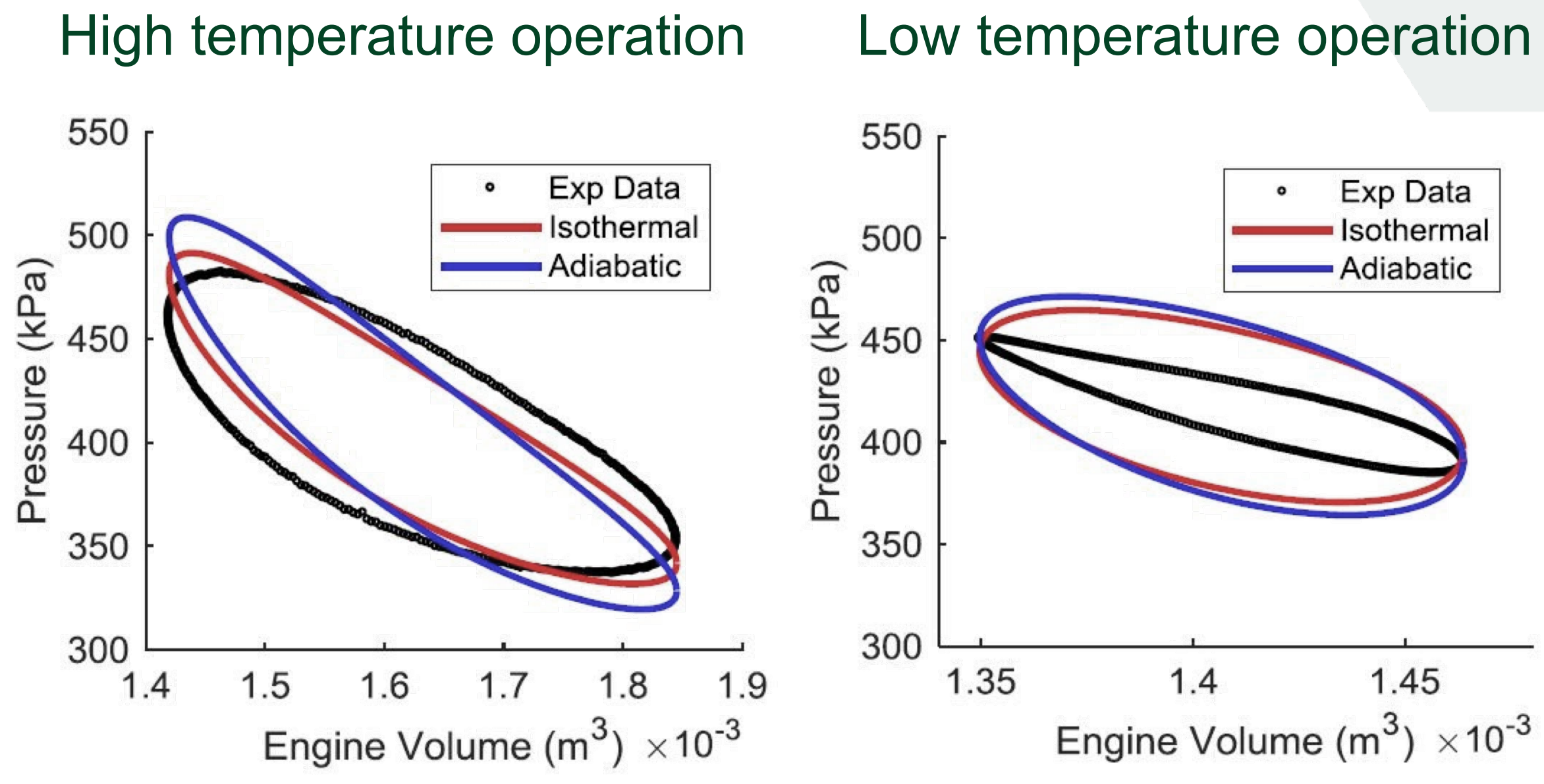
Carnot Efficiency	Beale Number	West Number	Convective Heat Transfer Equation
$\eta_C = 1 - \frac{T_C}{T_H}$	$N_B = \frac{\dot{W}_{shaft}}{f V_{swp} p_{mean}}$	$N_W = N_B \frac{(T_H + T_C)}{(T_H - T_C)}$	$\dot{Q} = hA\Delta T$

T_C: low temp. | T_H: high temp. | $\dot{W}_{shaft}$: power

f : frequency | V_{swp}: swept volume | p_{mean}: mean pressure

h: convective heat transfer coefficient | A: heat exchanger area

2nd Order Modelling


High temperature operation

Low temperature operation

Figure 1: Current Models and Comparison with experiment

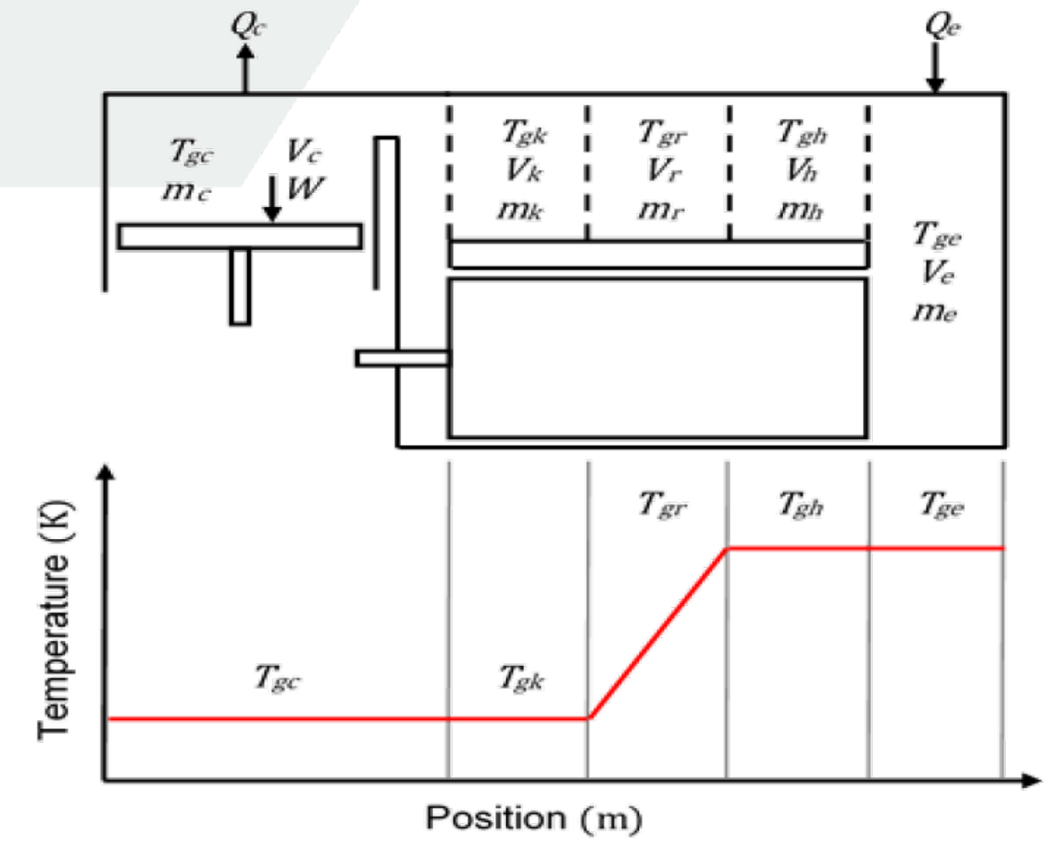
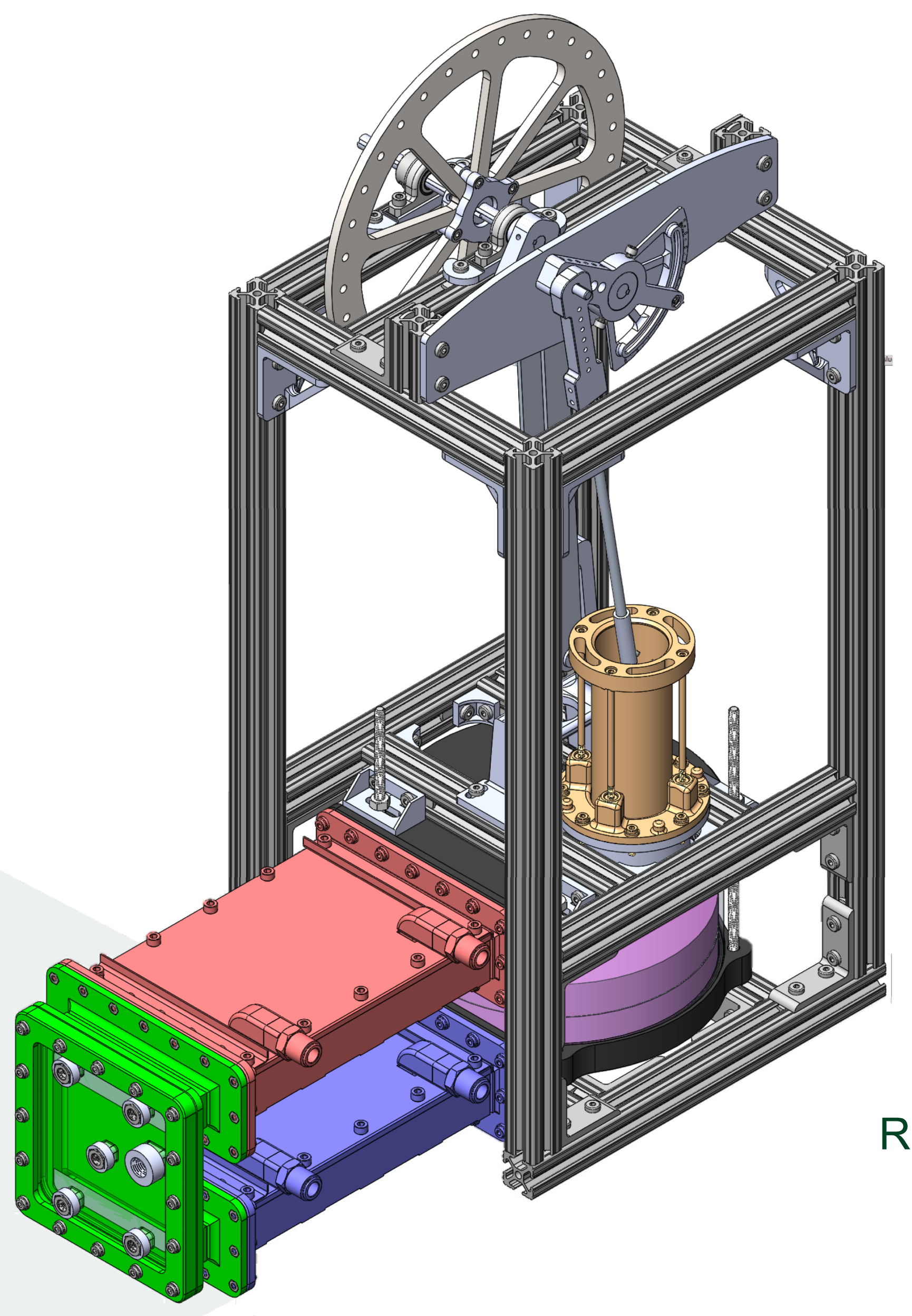


Figure 3: Ideal Isothermal Model

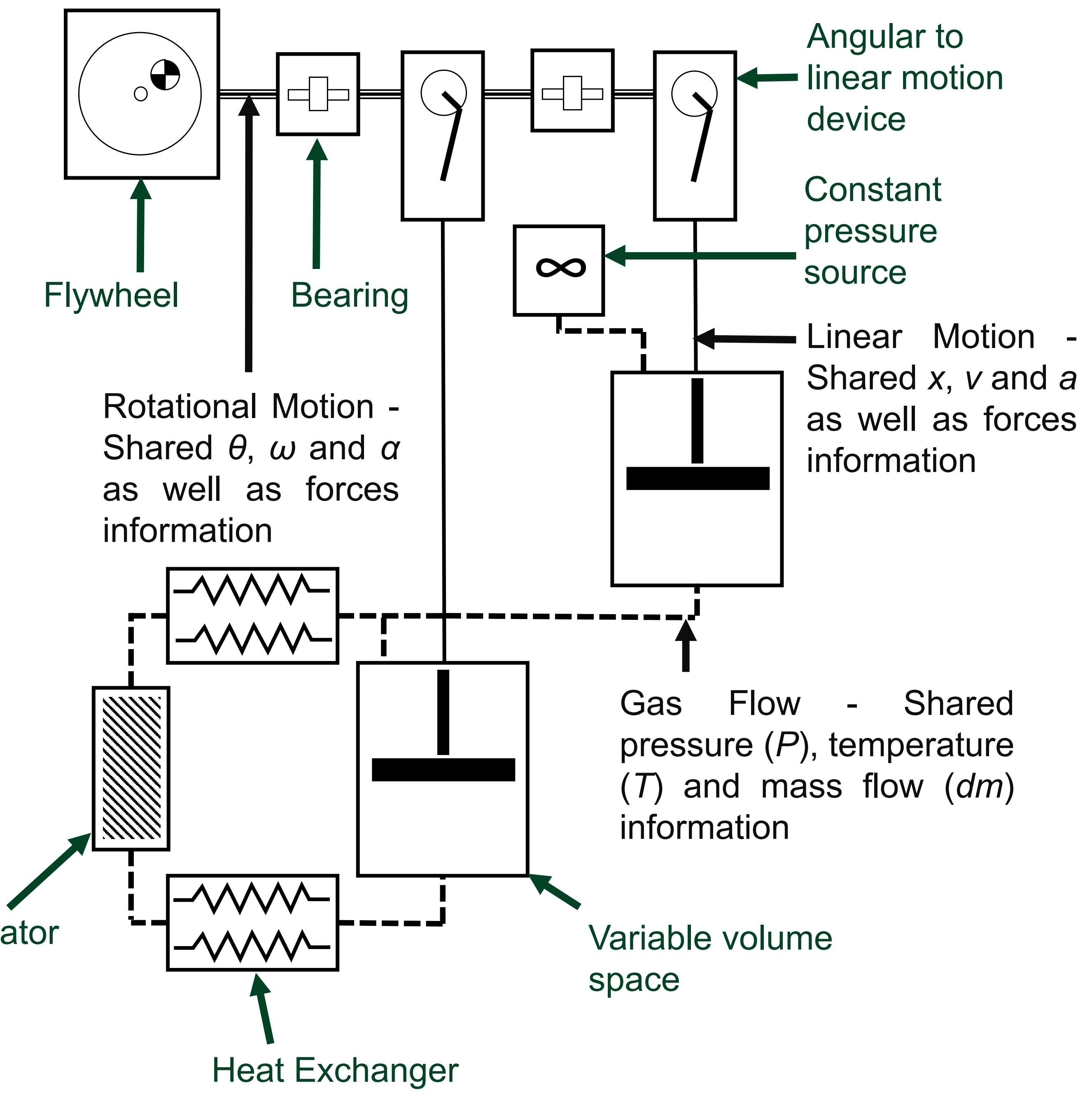
Current modeling approaches based on ideal cycles. The models allow losses to be added, but in a decouple fashion. No prediction of speed or power, only energy per cycle.

3rd Order Modelling

Stirling Engine Configuration



Component Identification



Angular to linear motion device

Constant pressure source

Linear Motion - Shared x, v and a as well as forces information

Flywheel

Bearing

Rotational Motion - Shared θ, ω and α as well as forces information

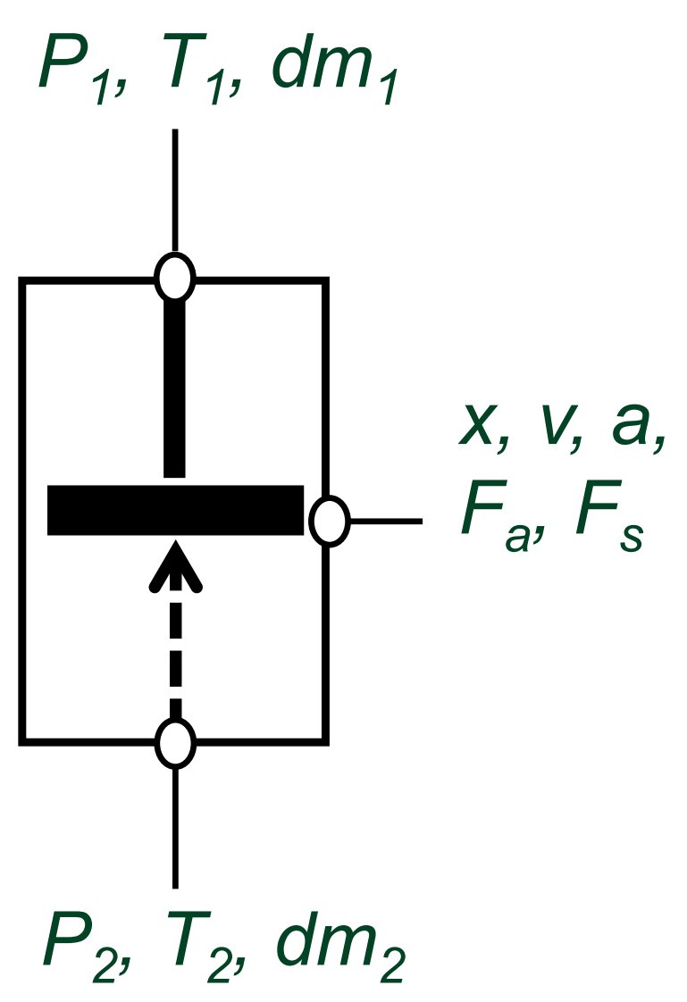
Gas Flow - Shared pressure (P), temperature (T) and mass flow (dm) information

Regenerator

Variable volume space

Heat Exchanger

Component Modelling



Equations internal to variable volume module (example)

$$dm = \rho A dx$$

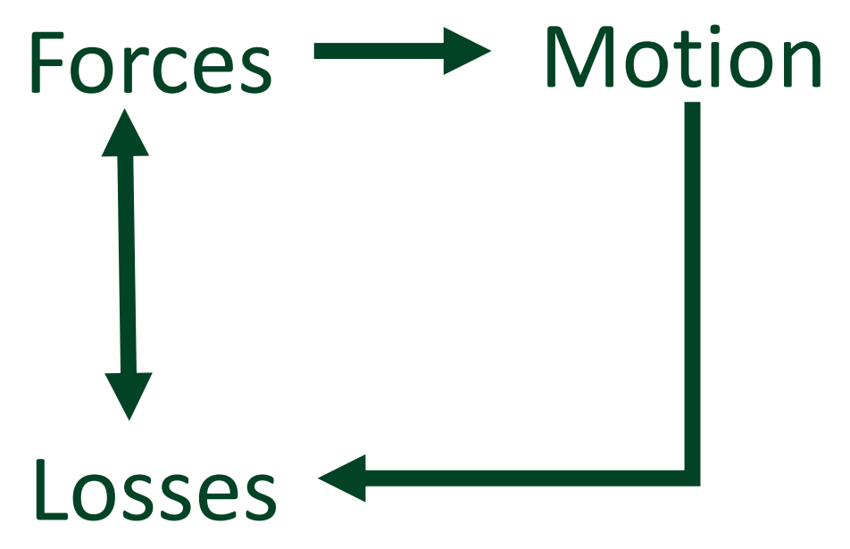
$$F_a = (P_2 - P_1)A + F_f$$

$$F_f = f(F_s, v)$$

$$\rho = \frac{P}{RT}$$

Losses are tracked within each component and take part in the force balance.

Dynamic Modelling



FUTURE DIRECTIONS

- Develop 3rd order model for optimum engine design
- Integrate the 3rd order model into the complete design environment for geothermal Stirling engine
- Use the 3rd order model as a bases for developing an active control model of a complete system

PARTNERS

- Alberta Innovates
- Terrapin Geothermics Inc.

FES PROJECT OVERVIEW

This Future Energy Systems (FES) project is part of the Geothermal Theme, entitled **Optimizing Geothermal Energy Production and Utilization Technology** (FES T05_P03) With the vast amount of energy available in geothermal reservoirs identified throughout Alberta, a new technology is need to access and convert this low grade heat into a useful form. This means converting available fluid temperatures, typically <100 ℃ into electricity or space heating. This project focuses primarily on the development of proof-of-concept and viability studies of ultra-low maximum temperature (ULT_{max}) Stirling engines, their design and the development of predictive models for system scale up and development

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