[Industrial paper] A New Library for Modeling and Simulation of Pneumatic Systems

Maximilian Kormann[1] Dr. Clément Coïc[2] Guillaume Viry[3]

[1]Dassault Systèmes, Germany, maximilian.kormann@3ds.com
[2]Dassault Systèmes, Germany, clement.coic@3ds.com
[3]Dassault Systèmes, Germany, guillaume.viry@3ds.com

Abstract

The Pneumatic Systems library (PSL) by Dassault Systèmes is aimed at modeling pneumatic power systems. Typically, such systems involve actuators in industrial plants, pneumatic brakes or suspension systems, etc. Also, this library suitable for aerospace applications such as cooling or engine bleed air systems. The library deals with common problems modelling fluid flow in Modelica like accuracy in throttles or multi-sided connectors.

Keywords: pneumatics, heat transfer, fluid model, pneumatic power, pneumatic system, fluid flow

1 Introduction

In the following section, basic attributes of the library are given.

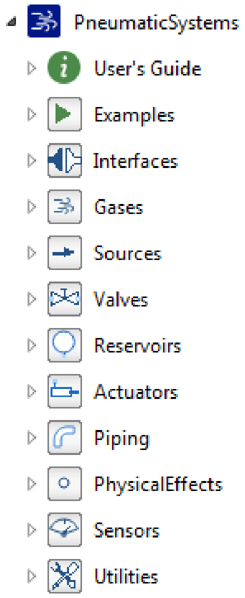

Figure 1. Library structure.

1.1 Library structure

An overview over the top level of the library is given in figure 1. To uncouple physics and their technical application, pneumatic systems' physical effects serve as the base class of the library object-orientation. These effects typically involve: capacitance, resistance, heat transfer and other power transformation (e.g. pneumatic to mechanical transformation).

Models of `Valves`, `Reservoirs`, `Actuators` and `Piping` instantiate or extend models from `Physical Effects` for technical application.

The `User's Guide` provides some tutorials based on `Examples` for getting started with the library.

1.2 Provided models

Different types of `Sources` define the origin of pneumatic power. Depending on the intended modeling depth, a simple pressure source can be used or the user can model a complex compression system utilizing the vane compressor model, for example.

`Valves` are used to control the fluid flow direction or imply a logic on the pneumatic system. `Actuators` transform pneumatic power into translational or rotational power. The icons of these components are compatible to (ISO 1219).

The most common example is a pneumatic cylinder. `Reservoirs` provide the possibility to store pneumatic power and/or apply heat transfer. `Piping` and `Restrictions` enable modeling the fluid transportation dynamics and losses.

2 Library features

In the following section, the advantages of the library will be outlined.

2.1 Fluid Model

Choosing the fluid model is done by instantiating a fluid model from the `Gases` package into the top level of the model. All deeper levels will access the fluid model by using the `outer` keyword. The fluid model is graphically represented in the top level as it can be seen in the lower left component in Figure 3.

The `Ideal Gas` model is suitable for most applications below temperatures of $500K$. Its gas equations are defined according to (White, 2016) and the dynamic viscosity is estimated by the law of (Sutherland, 1893). In order to improve the library compatibility and genericity an `ImportFromMSL` model is provided enabling to utilize any compressible fluid model from the Modelica Standard Library.

2.2 Symbols and Animation

The symbols in the icon layer of `Valves` and `Actuators` comply to ISO 1219. By default, the icons represent the current position of the valve or actuator during simulation to visualize the effects of a model. For complex models the animation can be deactivated to increase simulation performance.

2.3 Convenient computation of port properties

The variables in Table 1 have been chosen as properties in connectors. For enthalpy transport the stream concept (Franke et al., 2009) is being used. The templates for all PSL components (except multiple ports) contain a `GasProperties` class for each connector. By default, it is set to an empty class without computation of any values to increase performance. As the port variables can be insufficient for testing and debugging of a model, the choice is let to the user to replace `GasProperties` by other classes calculating total, static and/or critical (at sonic speed) values of the flow including density, temperature, viscosity, inner energy and more.

Table 1. Properties in a connector.

Formula sign	*Description*
$\dot{m}$	Mass flow through the connector
p	Absolute pressure in the connector
$h_{outflow}$	Specific enthalpy of the exiting flow

2.4 Discussion on kinetic energy

To estimate the mass flow through restrictions, most available formulas depend on the pressure ratio between downstream static pressure and upstream total pressure (Andersen, 1976). The calculation of static properties requires additional computational effort and may reduce the stability of the model. A slight inaccuracy is accepted for the benefit of improved simulation performance by setting `neglectKineticEnergy=true` by default for all components extending `PartialRestriction`. With this setting both total values for upstream and downstream pressures are being used to calculate the pressure ratio. If high accuracy is more important than computational speed, `neglectKineticEnergy=false` can be set.

2.5 Heat transfer

By default, all components are assumed to be adiabatic components. The first law of thermodynamics (Çengel and Boles, 1994) is applied without heat flow over the system border. Additionally, the user has two non-adiabatic options (see Figure 2): Environment heat transfer models heat losses of components due to their surface being exposed to environment temperature. External heat transfer provides a heat port for the component allowing the user to individually model the heat transfer of the component.

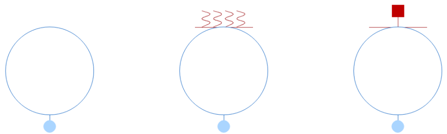

Figure 2. Adiabatic component, heat transfer to environment and to an external port.

3 Example

To describe the use of the library, an example will be given.

3.1 Description of the model

The example (see Figure 3) compares a pneumatic cylinder with cushioning to a cylinder without. Both cylinders are connected to a pressure source over a 3-2-Valve, which is actuated by a boolean pulse, to imply a cylinder movement. The rod of the cylinder is connected to a fixed spring damper system.

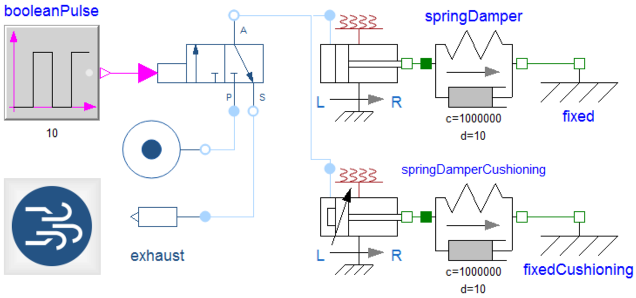

Figure 3. Example model comparing a cylinder with and without cushioning.

Cushioning means an end point damping for cylinders realized by the pneumatic throttle effect. When the distance between piston and end point is lower than a defined value, the area of the inlet restriction to the cylinder is reduced to throttle the fluid flow of the cylinder. As the cylinder movement is coupled to the fluid flow, this effect results in damping.

This example covers the main physical effects involved into pneumatics: capacitance as the gas volume inside the cylinder, restriction as the inlet flow restriction into the cylinder and transformation as the cylinder converts pneumatic into mechanic power.

3.2 Simulation results

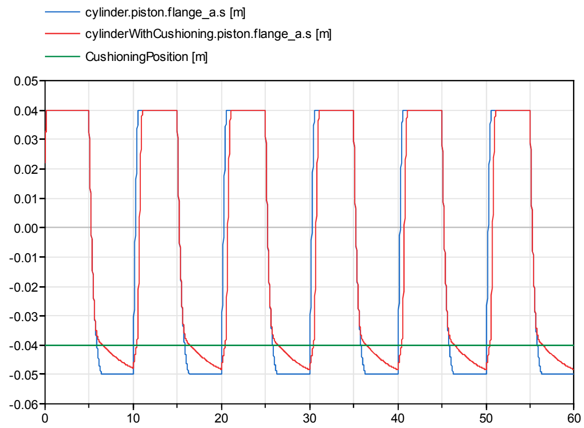

Figure 4. Comparison of the cylinder movement with and without cushioning.

As the example uses a one-sided cylinder, cushioning only happens on the left side of the cylinder actuation (see Figure 4). When the piston enters the cushioning zone (below the green line), the cylinder with cushioning (red plot) receives less mass flow rate from the inlet port and thus its speed decreases regarding the cylinder without cushioning (blue plot) and does not reach the same end position.

4 Conclusion

The Pneumatic Systems Library provides models for various applications of pneumatic power. The option to deactivate the neglecting of kinetic energy in orifices offers the possibility for more accurate simulations.

References

B. W. Andersen. *The Analysis and Design of Pneumatic Systems*. R.E. Krieger Pub. Co., University of Michigan, 1976. ISBN 1-575-24164-1.

Y.A. Çengel and M.A. Boles. *Thermodynamics: an engineering approach*. McGraw-Hill, 1994. ISBN 9780071132497.

R. Franke, F. Casella, M. Otter, M. Sielemann, H. Elmqvist, S. E. Mattson, and H. Olsson. Stream connectors – an extension of modelica for device-oriented modeling of convective transport phenomena. *Proceedings 7th Modelica Conference, Como, Italy*, pages 108–121, 2009. doi:10.3384/ecp09430078.

ISO 1219. Fluid power systems and components - graphical symbols and circuit diagrams, 2012.

W. Sutherland. The viscosity of gases and molecular force. *Philosophical Magazine 5*, pages 507–531, 1893.

Frank M. White. *Fluid Mechanics, Eighth Edition*. McGraw-Hill, 2016. ISBN 978-0-07-339827-3.