FUEL SYSTEM LIBRARY

Overview

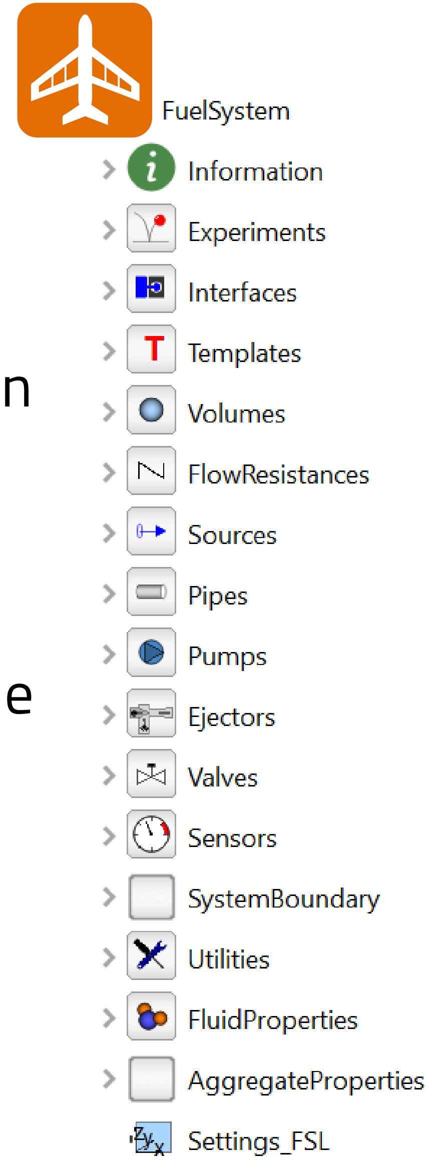
Modelon

AGENDA

- ❑ About Fuel System Library
- ❑ Key Benefits
- ❑ Key Capabilities
- ❑ Key Applications
- ❑ Library Contents
- ❑ Modelon Compatibility
- ❑ Latest Release: 2021.2

ABOUT FUEL SYSTEM LIBRARY

- Design and verification of fuel systems of civil and military aircrafts
- Analysis and verification of system behavior during various dynamic operating modes and flight conditions, including effects of large variations in acceleration, direction and altitude
- Provides simulation solutions to ensure robust fuel systems that deliver maneuverability in critical situations
- Models designed to be efficient and numerically robust to handle large-scale complex systems
- Easily realize non-standard circuits and failure modes by drag-and-drop system composition
- Full suite of component models including ejectors, tanks, valves, pipes, and atmospheres



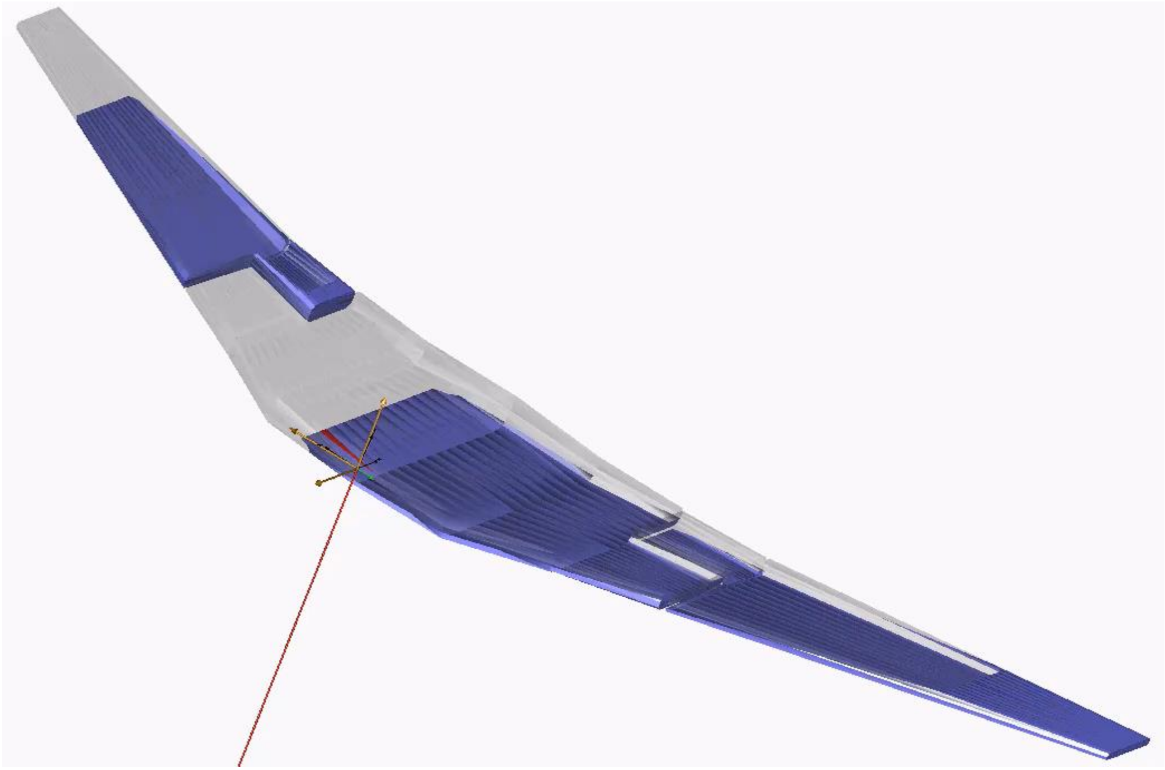
ABOUT FUEL SYSTEM LIBRARY

Offline simulation of complete Fuel Systems through complete flight envelope and all operating conditions:

- Large systems
- Controls, sequential and feedback

Real-time simulation of the same system models:

- Some simplifications, but the same overall model (real time capability achieved through model configuration selection)
- To be included in the special flight simulator hardware



KEY BENEFITS

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- High performance and real-time capable
- Import of 3D tank geometries from CAD
- Physics-based models covering thermal, hydraulics, inerting, evaporation, solubility
- Full support for bidirectional flow
- Efficient property models of air-fuel mixtures
- Easily switch off the thermal effects for faster simulations
- Easy integration with other libraries
    - Aircraft Dynamics Library
    - Jet Propulsion Library
    - Environmental Control Library
    - Vapor Cycle Library
    - Liquid Cooling Library
    - Heat Exchanger Library

KEY CAPABILITIES

KEY CAPABILITIES

Medium properties

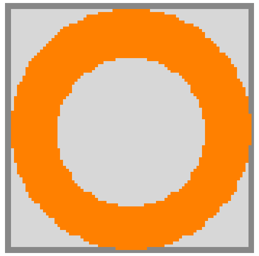
- Jet fuel
  - Jet-A, Jet-B, JP-4, JP-5, and JP-8
  - Liquid medium with slight compressibility
- Gas Mixture
  - Moist air (water with dry air or ideal dry air mixture)
    - No water condensation ($\phi < 100\%$)
  - Evaporated jet fuel with dry air mixture
- Mixture medium
  - All components can contain a gas mixture and liquid fuel in an arbitrary combination
  - Solubility of O2 and N2 gas in the liquid fuel

KEY CAPABILITIES

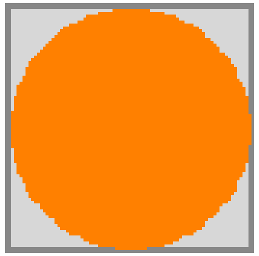
Multiple Connector types

Hollow connector

- pressure is a time continuous state
- used in interface of dynamic volumes



p as state
set position



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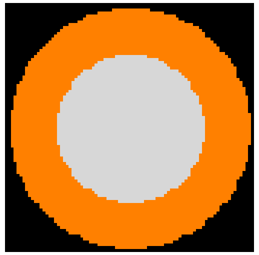
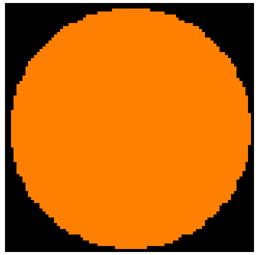


p as state
get position



p not as state
get position

Filled connector

- mass flow rate is computed from Dp
- used in flowmodel interfaces
- static eq: m_flow = f(Dp): valves, resistances, turbines, compressors

Efficient large models require alternating pressure and massflow computation ! !

KEY CAPABILITIES

Position information

Pipes

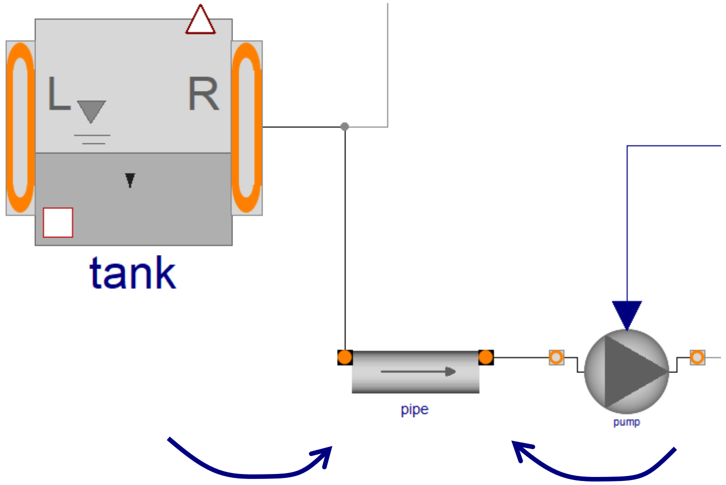
- Receive position information and cross sectional area from connected components
- Receive acceleration vector via inner/outer
- Optional dynamic momentum balance: pressure drop, static head and resistance losses can be computed from massflow as state

All other components

- Set position information and cross section for each connection point
    - Optional multibody frame connector can be enabled to set position
- Numerical states: p, T, X[1:nS-1]
- Acceleration is only accounted for in pipe and tank models

KEY CAPABILITIES

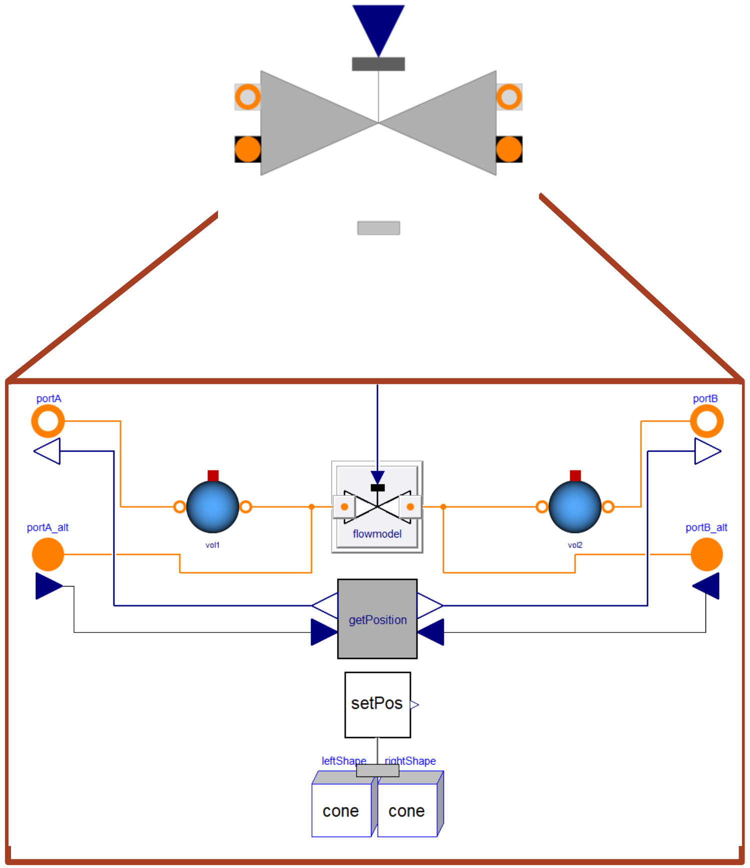
Position information



flow area
+ 3D-position

flow area
+ 3D-position

+ pipe length
+ projection of acceleration vector on pipe length



fuel system valve=general fluid system valve + dynamic volumes (optional)
+ positioning information
+ fuel system connectors

similar procedure for
- pumps
- resistances
-...

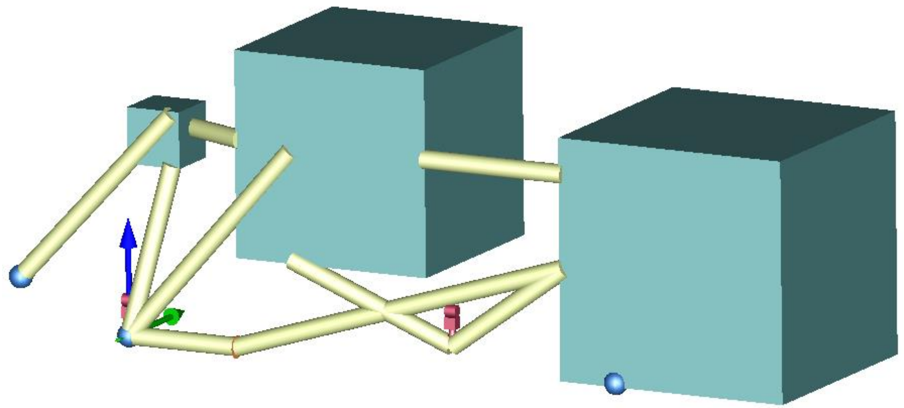
KEY CAPABILITIES

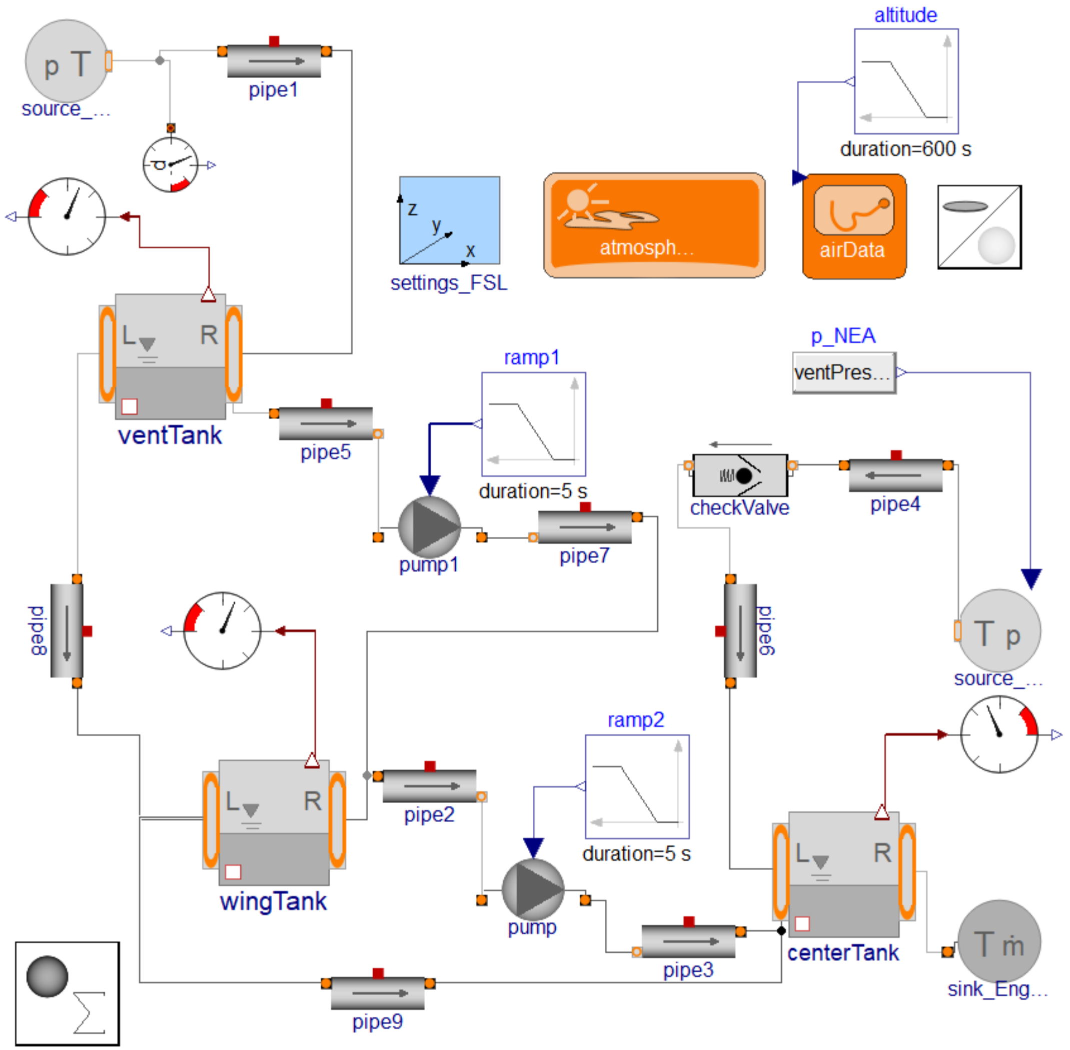
Fuel tank inerting

Purpose:

- Fill air space in tanks with inert gas (N2) to reduce concentrations of oxygen and fuel to prevent combustion

Medium properties use dry air mixture with variable composition of O2 and N2





KEY CAPABILITIES

Fuel evaporation

Purpose:

- Track amount of evaporated fuel in ullage

Medium properties package for fuel evaporation

- Evaporated jet fuel, O2, N2 and liquid jet fuel
- Jet-A, JP-4, JP-5, and JP-8

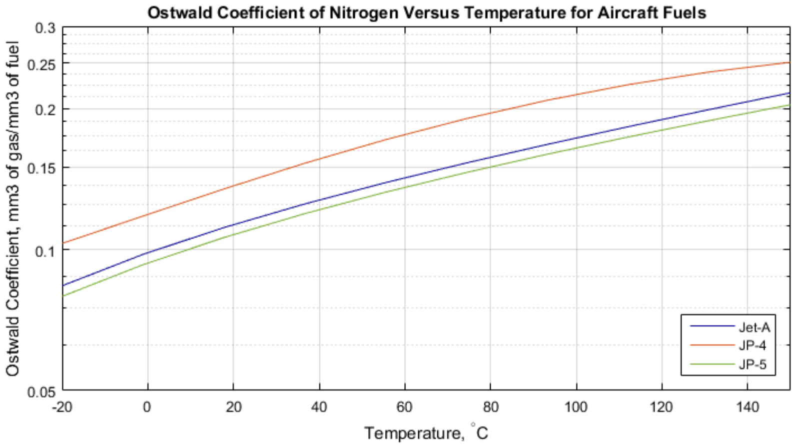
Amount of evaporated fuel is based vapor pressure

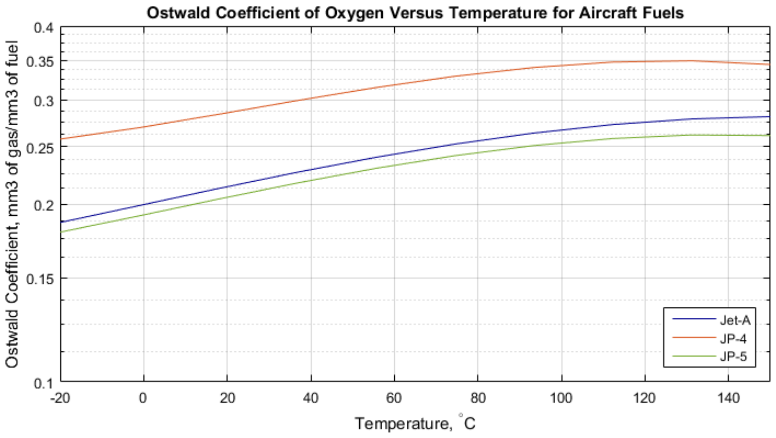
Jet fuel pseudo compound modeled in liquid and vapor phases

KEY CAPABILITIES

Gas solubility

- Tracking trace concentrations of oxygen and nitrogen dissolved in the liquid jet fuel
- Assume dissolved gas does not alter thermodynamic properties of fuel or gas
- Assume first order rate equation for dissolution and outgassing
- Use data from the Aviation Fuel Handbook for Ostwald coefficients for Jet-A, JP-4, and JP-5

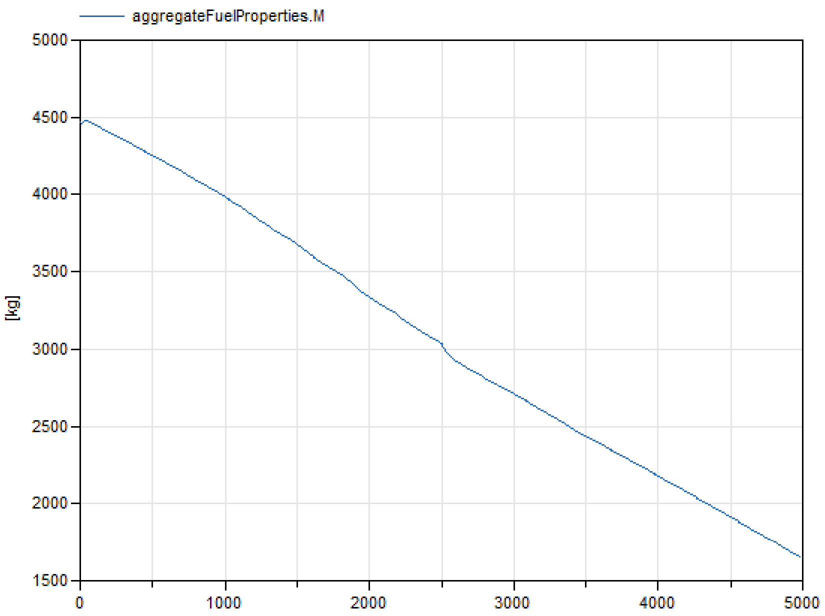


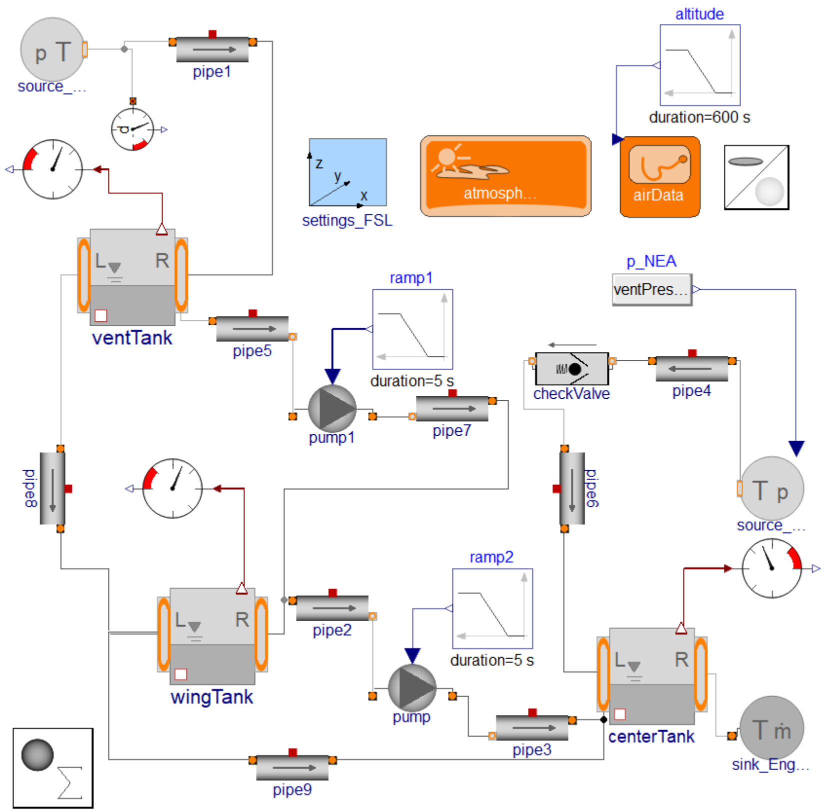


KEY CAPABILITIES

Aggregation of Fuel mass

Automatically tracks total mass of fuel in large systems





KEY APPLICATIONS

KEY APPLICATIONS

Real-time

Scope:

- Develop complex and accurate models that can be run in real time
- Use the same high-fidelity models throughout the design and validation process

Relevant solution features:

- Fuel Systems Library real-time mode
- Inline integration
- Mixed-mode integration

KEY APPLICATIONS

Inerting

Scope:

- Analyze the dynamic propagation of species like nitrogen and oxygen
- Size the inerting system to ensure admissible oxygen concentrations throughout the envelope

Relevant solution features:

- Dynamic balance equations including full support of flow reversal
- Set venting boundary conditions through ambient model

In particular:

- Gas mixtures distinguishing O2 and N2

KEY APPLICATIONS

Fuel transfer/refueling

Scope:

- Dynamically simulate fuel transfer and refueling of aircraft
- Validate line, orifice, pump/ejector and balance tube performance
- Simulate failure conditions including ejector induced and discharge flow reversal and pump cavitation

Relevant solution features:

- Ideal tank volume sensors
- Impose arbitrary aircraft altitude and attitude
- Visualization of simulation results

In particular:

- Arbitrary tank geometries to accurately predict level-volume relations

KEY APPLICATIONS

Flammability

Scope:

- Dynamically simulate mass and energy balance
- Assess temperatures in relation to flash point/lower and upper flammability limits
- Model heat transfer, mass transfer, solubility

Relevant solution features:

- Heat transfer to gas and liquid
- Convective transport of mass and energy

In particular:

- Evaporation of fuel
- Solubility of oxygen and nitrogen in fuel
- Heat transfer correlations

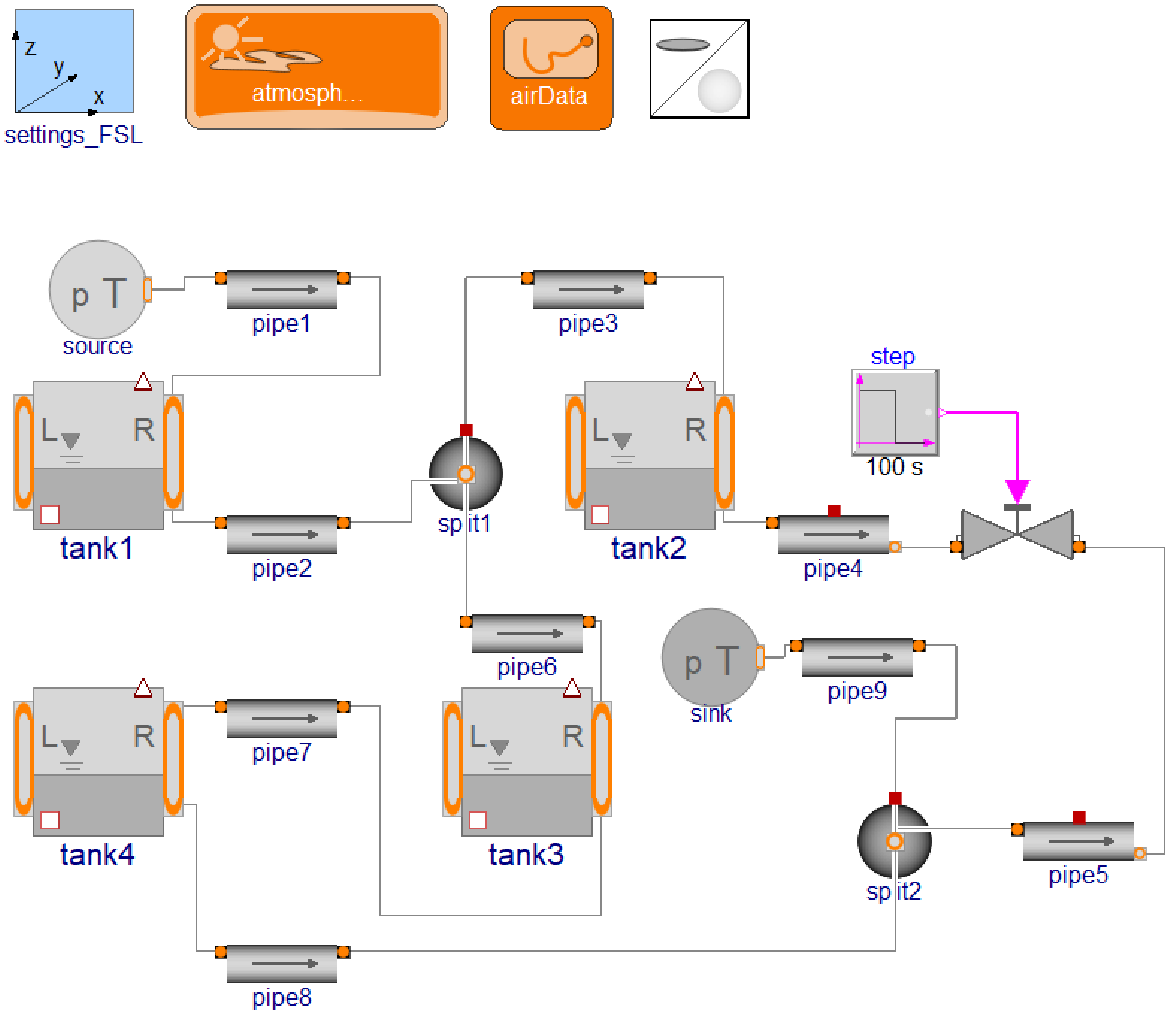
EXAMPLE: FILLING TANK

Quasi-steady-state components:

- Settings_FSL (1), AirData(1), Atmosphere(1)
- Pipe (8)
- Valve (1)
- Sinks/sources (2)

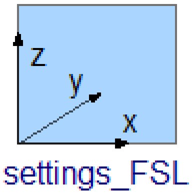
Mass and energy storage:

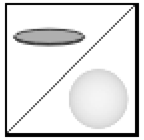
- Tank (4)
- Dynamic volumes (incl. e.g. moisture condensation) (2)



LIBRARY CONTENTS

COMPONENTS





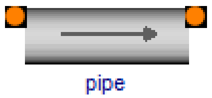
Systems of Aircraft fluid

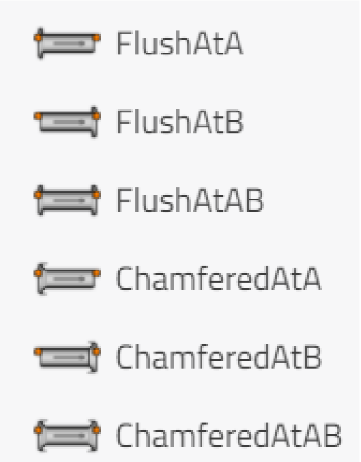
- System settings like altitude, Mach number, etc

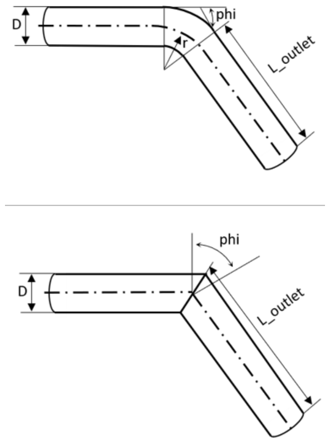
Boundary conditions

- Pressure source/sink
- Mass flow source/sink
- Options: set parameters, signal inputs, use atmosphere information from system component

Pipe





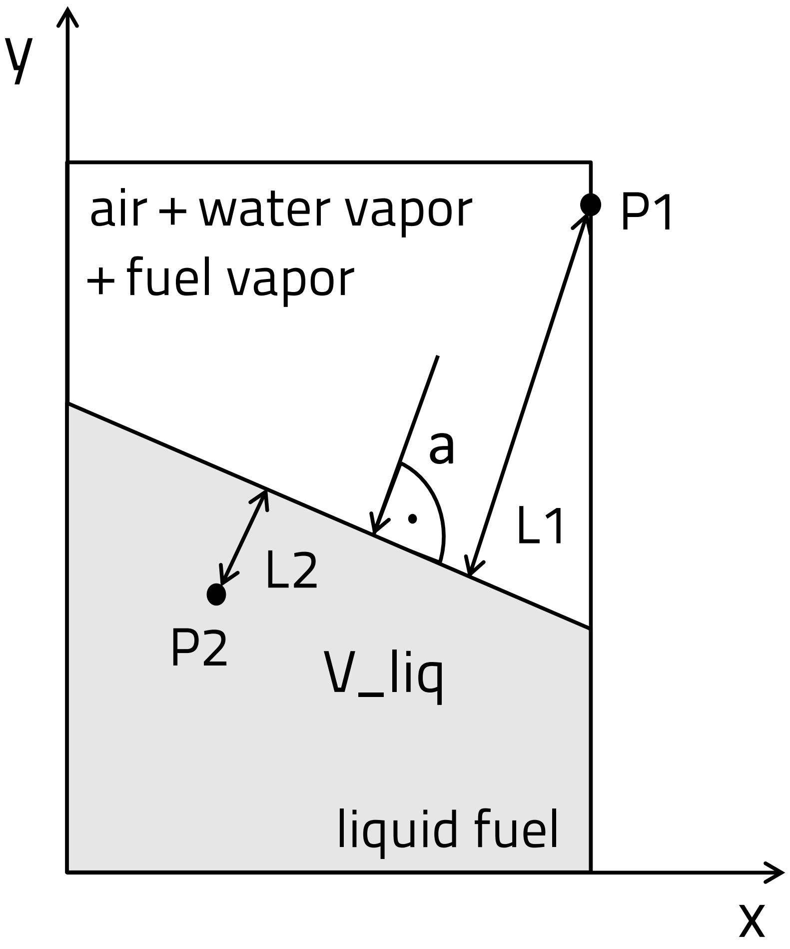


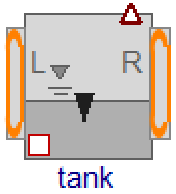
- Static head uses connection vector between ports
- Friction model requires total length, including bends
- Geometric pipe models with the inbuilt calculation of loss coefficient are available

COMPONENTS

Tank

- Volume with one pressure and temperature state
- Distance of liquid level to port determines port pressure – iteration variable or additional numerical state
- Ports can be left unconnected
  - input: P1, P2, a, V_liq
  - output: L1, L2
  - acceleration a: arbitrary 2D vector



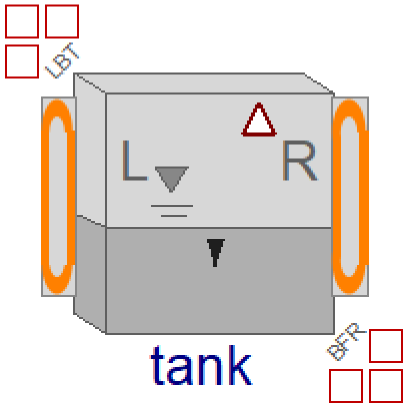


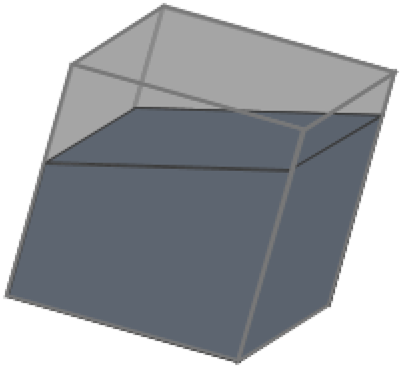
component icon

COMPONENTS

Tank with Heat Transfer

- Volume with one pressure and temperature state
- Heat port for each side of the box shaped tank
- Calculate wetted surface area for each side
- User-defined wet/dry heat transfer coefficient for each side

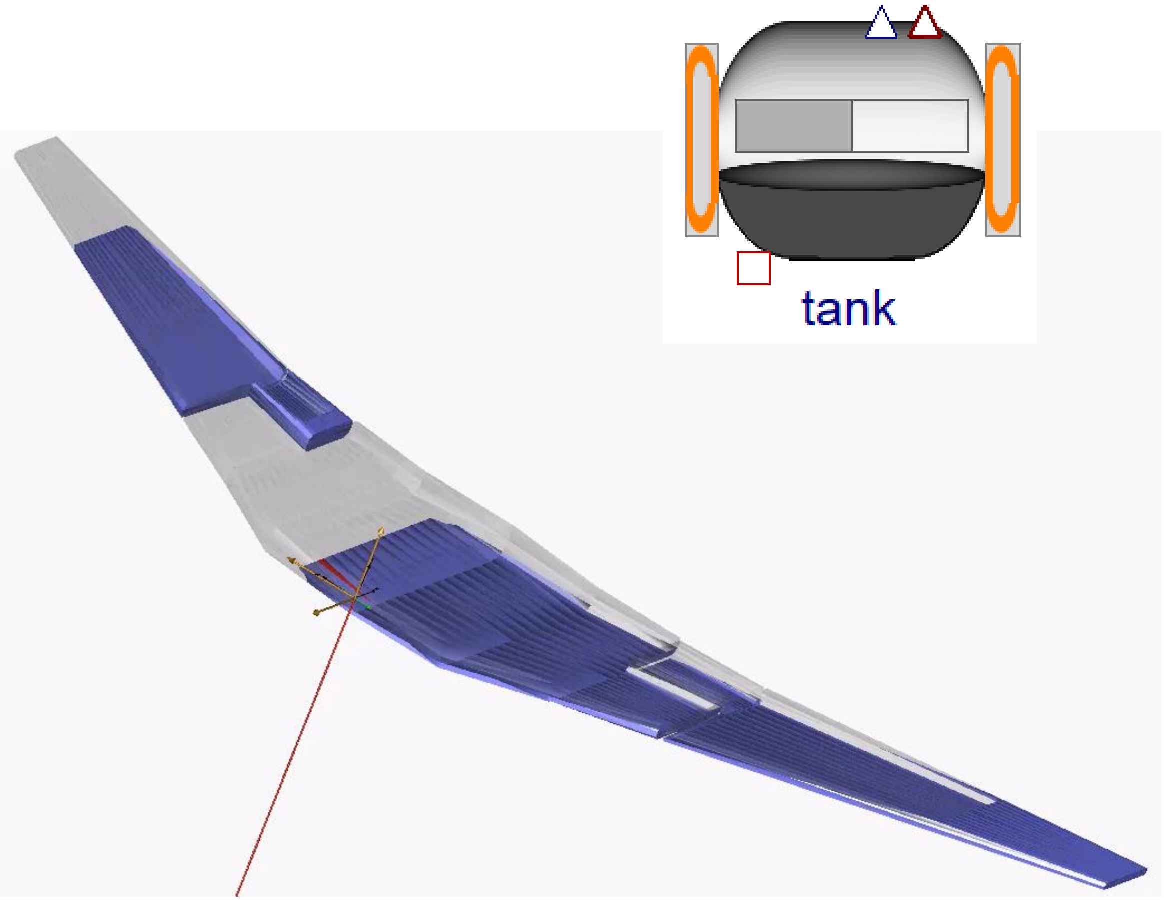




COMPONENTS

Complex Tank

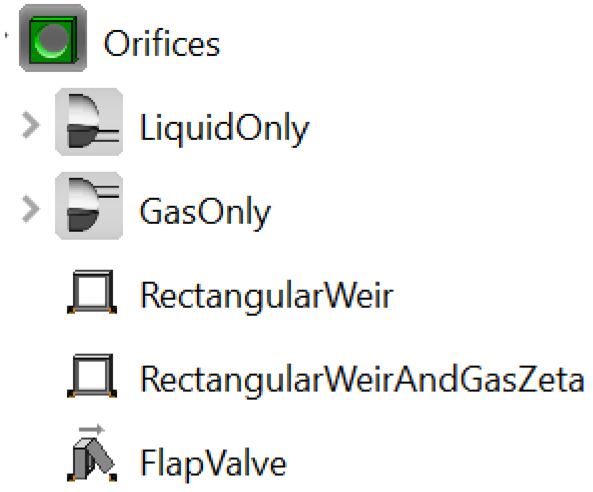
- Geometry defined by sets of vertices and triangles
- Supports import of CAD geometries via STL files
- Arbitrary number of heat transfer surfaces
- Physical free convection heat transfer correlations distinguishing wet vs. dry surface, surface inclination etc.

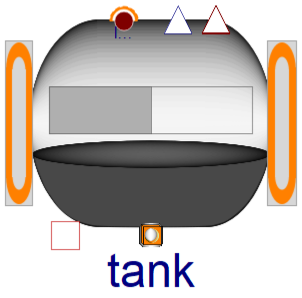


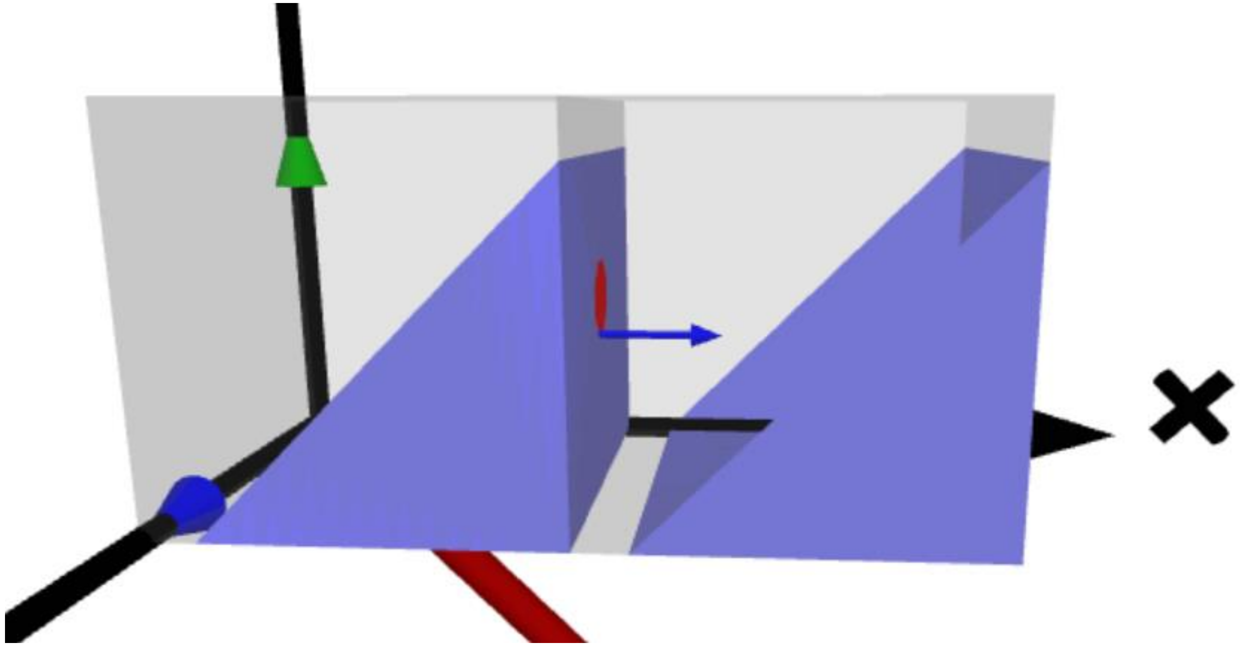
COMPONENTS

Multi-Level Tank

- Simulate the behavior of a tank where basins are not communicating in certain configurations and thus can have different liquid levels in the same tank system
- Tanks are modeled orifice models connected in-between
- Geometry defined by sets of vertices and triangles
- Supports import of CAD geometries via STL files



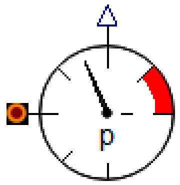




COMPONENTS

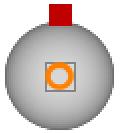
Ideal Sensors

- Single port sensors: p, T
- Two port flow sensors: m_flow, V_flow



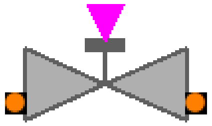
Volume

- Dynamic energy and mass balances
- Volume without hydraulic resistance



Valves

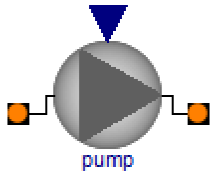
- Check valve
- Control valve (Kv-value parameterization)



COMPONENTS

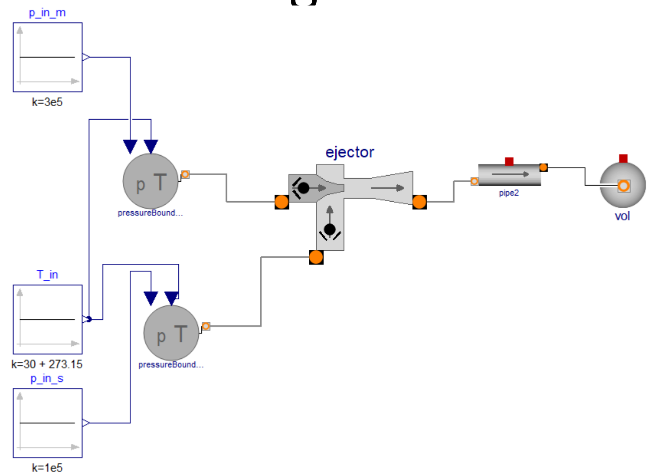
Pump

- Hydraulic characteristics
- Power characteristics
- Cavitation influence by a reduction factor by parameterization



Ejector

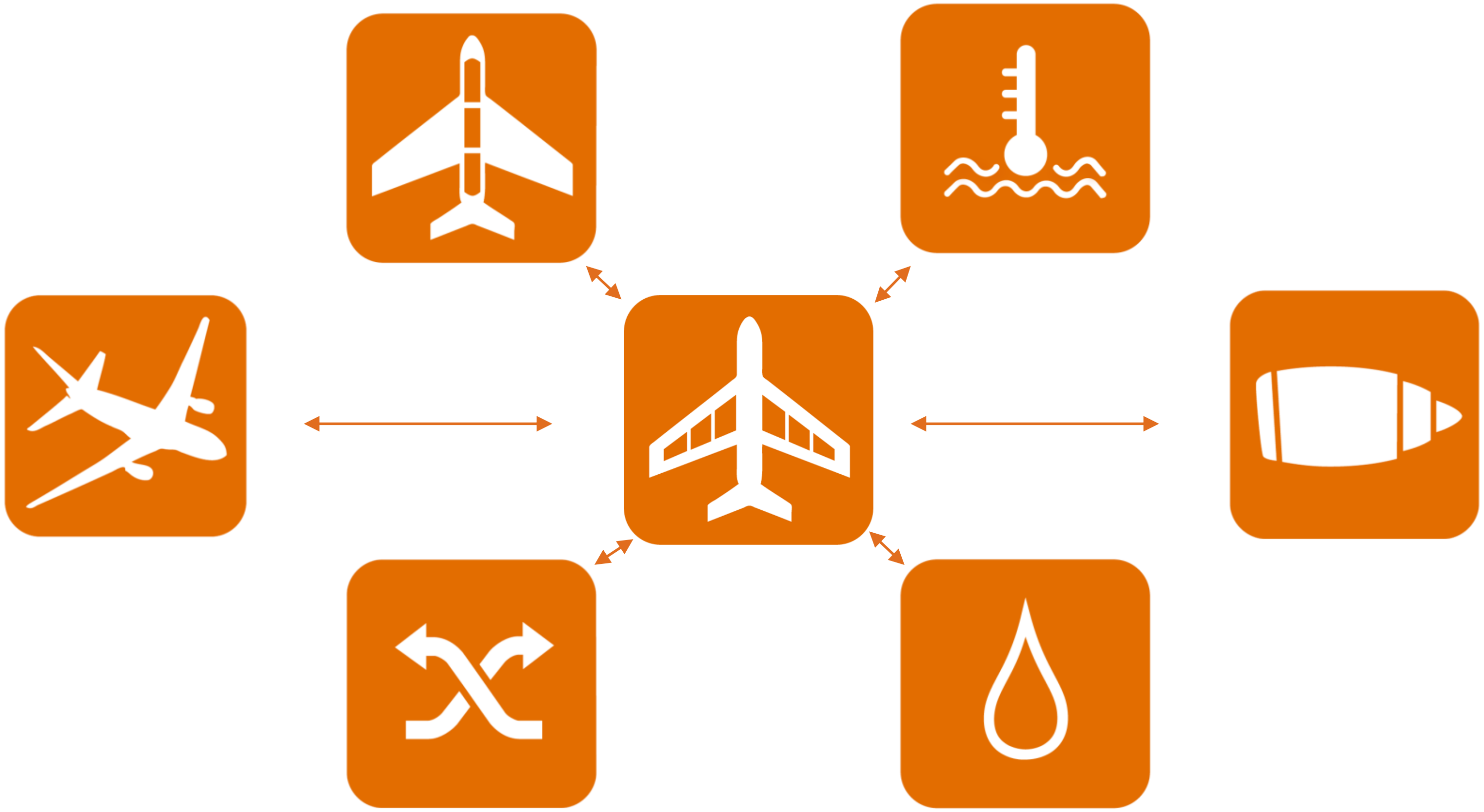
- The motive flow is always positive, induced and discharge flow can change flow direction
- Choked flow is not reached in the nozzle
- Incompressible
- Friction losses
- Two variants:
    - Friction coefficient
    - ESDU



MODELON COMPATIBILITY

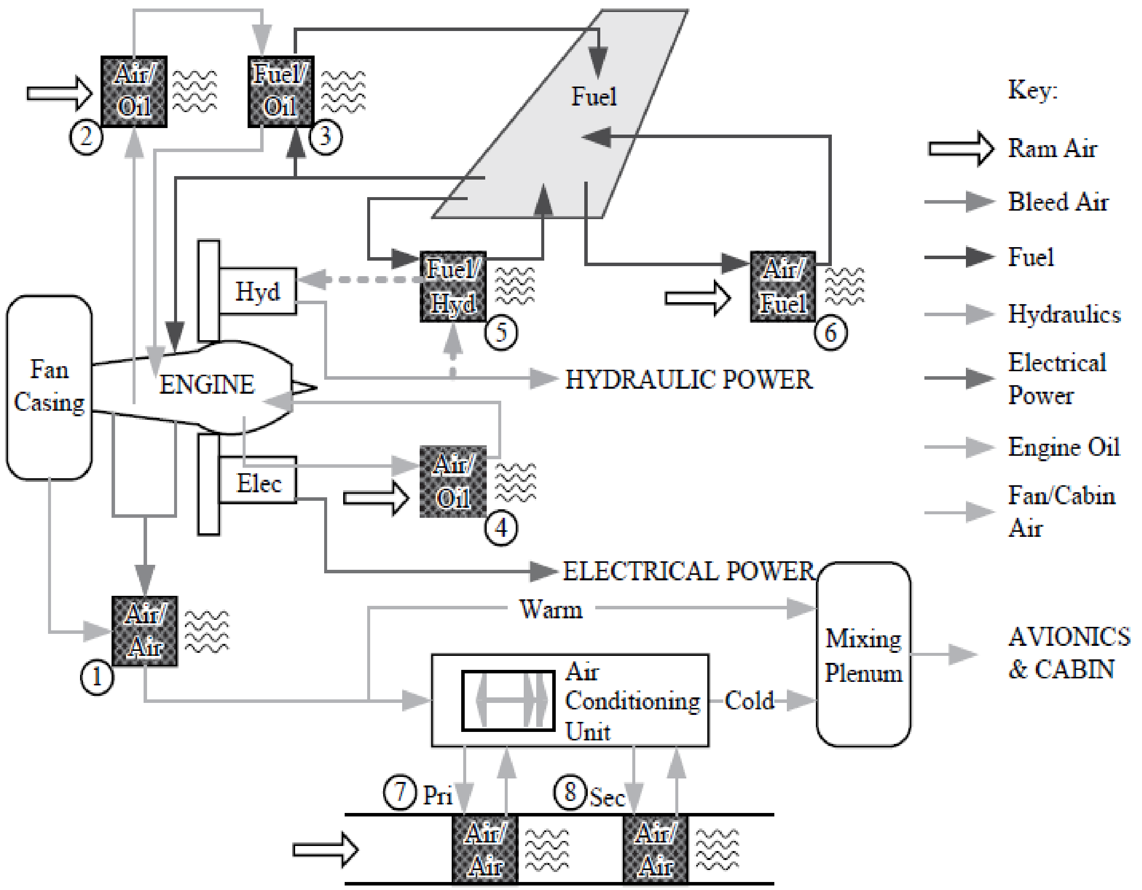
RECOMMENDED MODELON LIBRARY COMPATIBILITY

- Environmental Control Library
  - Moist air
  - Turbines
  - Fans
  - Compressors
  - Ejector
- Aircraft Dynamics Library
- Jet Propulsion Library
- Liquid Cooling Library
- Heat Exchanger Library
- Hydraulics Library



EXAMPLE: MODELON PORTFOLIO MULTI-DOMAIN SYSTEM

- Electric Power Library
- Environmental Control Library
- Fuel System Library
- Heat Exchanger Library
- Hydraulics Library
- Liquid Cooling Library
- Vapor Cycle Library



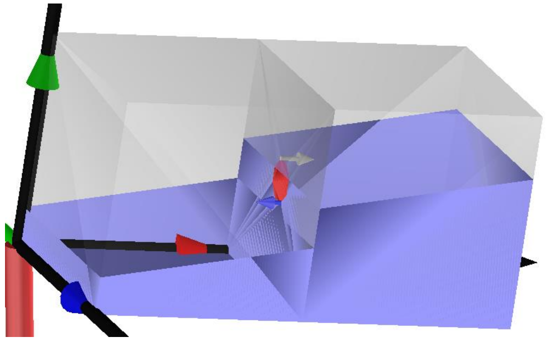
Modelon

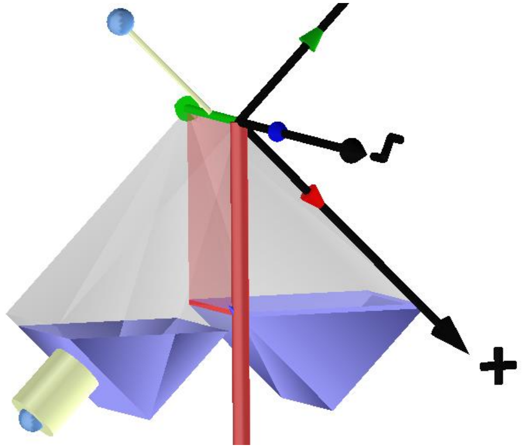
LATEST RELEASE: 2021.2

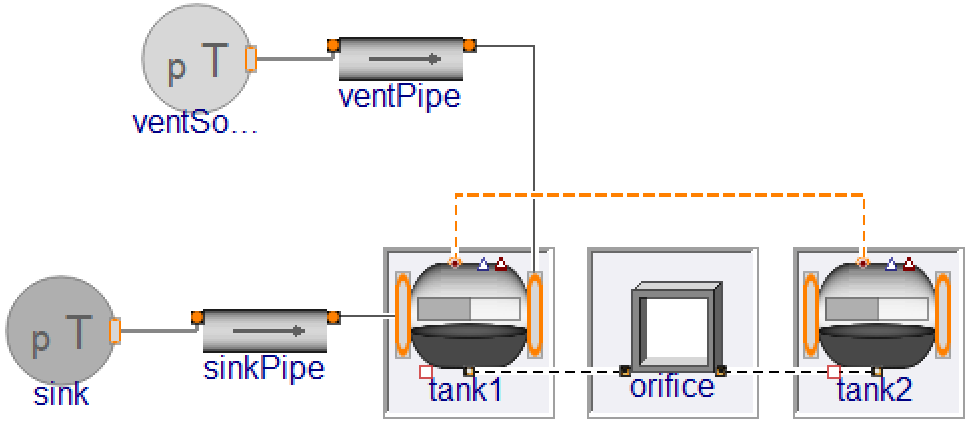
RELEASE: 2021.2

New Feature

- A new complex geometry tank model supporting multi-level simulations is added. The flow through the tanks are modeled by an orifice approximating a rectangular weir as opening.
- Devices to extract only liquid or gas from the multi-level tank are added.
- Add ControlValveIncompressible
- Added new Re-entrant intake and Orifice liquid friction models.
- Added new geometric pipe models with the inbuilt calculation of loss coefficient.







RELEASE: 2021.2

Enhancements

- Added a Boolean parameter visualize to the tank geometry kernels (ModelicaWithVisualization and ExplicitExternalWithVisualization) which supports 3D visualization. By default, it is set to true. Setting this to false will reduce result file size and simulation time considerably.
- Aggregate CG computation across all tanks is updated to weighted average CG of tanks, Σ(CG*M)/ΣM.
- Added option paraOption_Xliq to MassFlowBoundary and PressureBoundary to impose liquid fraction via signal input (in addition to existing option to enter this via a parameter).
- Improved assert conditions in LumpedPipe to capture all false pressure loss settings.
- Added documentation in LumpedPipe explaining connecting a pipe with a tank.