D5.5	**Aircraft Vehicle Systems Benchmark Models**
Access[1]:	**CO, PU**
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Due Dates[3]:	**M12, M24**

Open Cyber-Physical System Model-Driven Certified Development

Executive summary[4]:

This deliverable includes benchmark simulation models in the form of Functional Mock-up Units (FMUs). The models are representing different aircraft vehicle systems with focus on cooling systems, and are developed using both commercial and Saab proprietary Modelica libraries. The FMUs are primarily intended for use in the development and evaluation of the FMI Master Simulation Tool with respect to parallelization techniques, FMI-TLM interoperability, general model/FMU management, and for the OpenCPS Aircraft Vehicle Systems Demonstrator (D6.3).

[1] Access classification as per definitions in PCA; PU = Public, CO = Confidential. Access classification per deliverable stated in FPP.
[2] Deliverable type according to FPP, note that all non-report deliverables must be accompanied by a deliverable report.
[3] Due month(s) according to FPP.
[4] It is mandatory to provide an executive summary for each deliverable.

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6 Deliverable leader according to FPP, role definition in PCA.
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8 Typically person(s) with appropriate expertise to assess deliverable structure and quality.
9 Status = "Draft", "In Review", "Released".

CONTENTS

ABBREVIATIONS

List of abbreviations/acronyms used in document:

Abbreviation	**Definition**
CS	Co-Simulation
ECS	Environmental Control System
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Unit
FSL	Modelon Fuel System Library
LAB	Saab in-house experimental Modelica library
ME	Model Exchange
MF	Modelica.Fluid
MFL	Modelica Fluid Lite
MSL	Modelica Standard Library
MST	Master Simulation Tool
TLM	Transmission-Line Method

1 INTRODUCTION

Aircraft vehicle systems are found in more or less any conventional aircraft, enabling fundamental capabilities necessary for aircraft operation. Examples include electrical and lighting systems, Environmental Control Systems (ECS), landing gear, fuel systems, and hydraulic systems. For fighter aircraft, emergency escape systems are also commonly included in this group. Vehicle systems are often technically complicated, including a vast number of hardware components as well as extensive software for control, functional monitoring, redundancy management, and Built-In Test (BIT). Typically, vehicle systems are tightly integrated into the aircraft, and due to the complexity of each subsystem and the high level of interconnection between subsystems, there are often significant challenges in engineering design at both subsystem and system level [1]. This deliverable includes FMUs representing different aircraft vehicle subsystems, with varying level of complexity.

1.1 Purpose of the Deliverable

The purpose of this deliverable is to provide industrially relevant examples of aircraft vehicle system models for use in the OpenCPS project, in WP2, WP5, and WP6. The models are primarily intended for use in the development and evaluation of the FMI Master Simulation Tool (MST) with respect to parallelization techniques, FMI-TLM interoperability, general model/FMU management, and for the OpenCPS Aircraft Vehicle Systems Demonstrator (D6.3).

To enable continuous tracking of the FMI Master Simulation Tool (MST) development, during the project but also after the project, this M24 version of the deliverable is publicly available.

2 FMI SETTINGS

The FMUs are generated from Dymola 2017 and Dymola 2018 using FMI 2.0. Some FMUs for Model Exchange (ME) are included in the deliverable, but due to the focus of the project the majority of FMUs are for Co-Simulation (CS). 32-bit and 64-bit FMUs for Windows are provided. Most CS FMUs includes the CVODE solver, and some includes the Dymola specific version of the Dassl solver, see the *modelDescription.xml* for each FMU.

3 MODELICA LIBRARIES

With the purpose to ensure industrial relevancy, four different Modelica libraries applying different modeling approaches have been used for benchmark model development; i) the Saab proprietary in-house library Modelica Fluid Lite (MFL) using algorithms and a signal-based causal connector approach in combination with simplified medium models, ii) the Modelica.Fluid (MF) of the Modelica Standard Library (MSL) using equations and an acausal connector approach in combination with detailed medium models, iii) a Saab proprietary in-house prototype library called LAB using equations and an acausal connector approach in combination with simplified medium models, and iv) Modelon Fuel System Library (FSL) using equations and an equation-based connector approach in combination with detailed medium models. In addition, some models are developed using basic components/blocks from MSL.

Figure 3-1 to Figure 3-3 shows the graphical layout of simple test models based on MFL, MF, and LAB respectively.

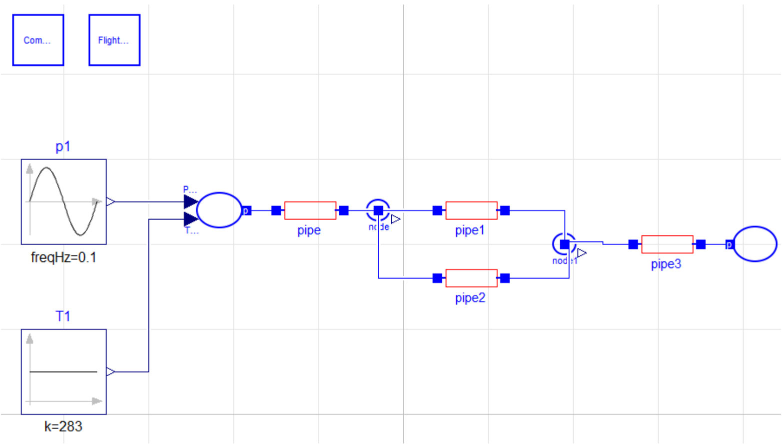

Figure 3-1: Simple test model based on MFL.

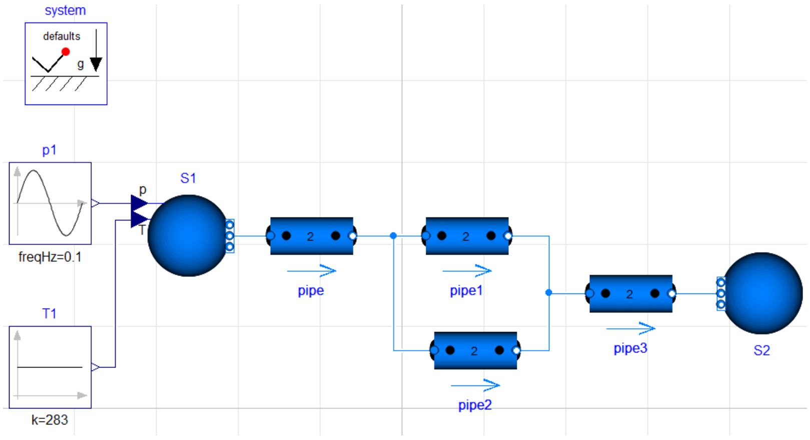

Figure 3-2: Simple test model based on MF.

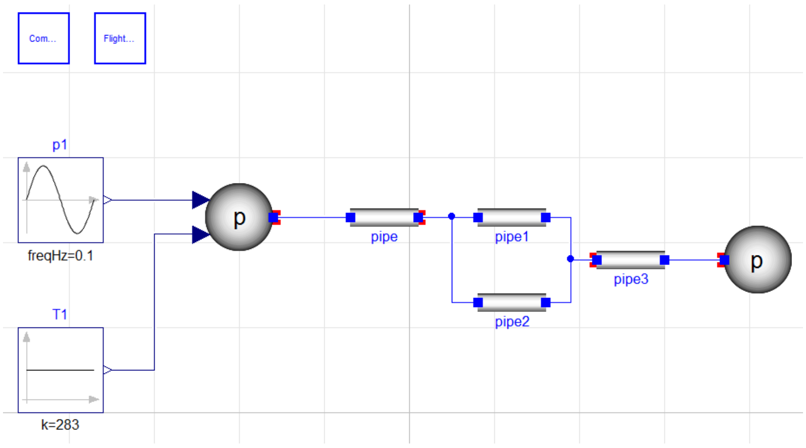

Figure 3-3: Simple test model based on LAB.

4 STRUCTURE & BRIEF DESCRIPTION OF FMUs

This section lists and briefly describes each FMU. For detailed information, see the *modelDescription.xml* for each FMU and documentation in [2]. The models may be used stand alone, or connected to form a prototype version of the OpenCPS Aircraft Vehicle Systems Demonstrator (D6.3). The relevant connections are provided by the composite model file *ecs-prototype.lua*. The Modelica library used as origin is indicated in parenthesis for each FMU below.

- Demonstrator
  - BC (MFL): Boundary Conditions in terms of time varying signals for e.g. altitude and Mach.
  - Cockpit (MFL): Simple representation of an aircraft cockpit, regards pressure calculation.
  - Consumer (MFL): Simple representation of a consumer of conditioned air.
  - ECS_HW (MFL): Detailed model of the hardware parts of an ECS intended to provide air supply, cabin pressurization, cabin temperature control, and avionics cooling. Bootstrap configuration using engine bleed air which is decreased in pressure and temperature and dried prior to distribution. As for any typical ECS, the main hardware components are heat exchangers, compressor, turbine, water separator, pipes, and control valves.
  - ECS_SW (MSL): Software model for controlling ECS_HW.
  - Engine (MFL): Simple representation of an aircraft engine.
  - TLM_Node (MFL): TLM compatible node component for pressure calculation
- Demonstrator extended
  - FS_HW (FSL): Detailed model of the hardware parts of an aircraft fuel system, feeding fuel to the engine and balancing the aircraft centre of gravity.
  - FS_SW (MSL): Software model for controlling ECS_HW.
  - Liquid Cooling (MFL, LAB, MF): A package of generic simple and more detailed liquid cooling system models, including FMUs for scalability tests.
- TLM interpolation
  - Interpolation (MFL): FMU consisting of a pressure source connected to a volume element via a pipe. Two instances of this FMU are to be connected using a TLMSimulator physical connection. The FMU includes an interfacing wrapper that interpolates input pressure for FMU internal time points in between communication points. This functionality is one way to facilitate interoperability between FMI and TLM; this FMU is developed to verify the interoperability
  - InterpolationReference (MFL): FMU consisting of a pressure source connected to a volume element via a pipe. Two instances of this FMU are to be connected using a TLMSimulator physical connection. Input pressure is provided at the communication points, the pressure in between these communication points is established through constant extrapolation.

- AlgebraicLoop
  - AlgebraicLoop_A (MFL): FMU that generates an algebraic loop during initialization when connected to the FMU AlgebraicLoop_B
  - AlgebraicLoop_B (MFL): FMU that generates an algebraic loop during initialization when connected to the FMU AlgebraicLoop_A

REFERENCES

[1] M. Eek, On Credibility Assessment in Aircraft System Simulation, Linköping: Linköping University, 2016.

[2] R. Hällqvist, R. Braun and P. Krus, "Early Insights on FMI-Based Co-Simulation of Aircraft Vehicle Systems," in *Proceedings of The 15th Scandinavian International Conference on Fluid Power* , Linköping, 2017.