A Heterogenous Modeling and Simulation Framework for Aero Engine Controller Model Performance Assessment

VIVEKANAND GURUPADAYYA SANJAWADMATH[1], R. SURESH[2], MATE NILESH[3]
[1]*Scientist, Instrumentation and Control Group, GTRE, Bangalore, Karnataka state, India*
[2] *Professor and Dean, Dept. of Chemical Engineering, RVCE, Bangalore, Karnataka state, India*
[3] *Scientist, Instrumentation and Controls Group, GTRE, Banaglore, Karnataka state, India*

Abstract*— A developmental Aero Engine Digital Engine Control System (AEDECS) is a multi-domain system comprising electronic controller with embedded software, hydro-mechanical components and electrical harness connecting these subsystems. AEDECS controls the aero engine throughout its operating regime. A heterogeneous, Advanced Model-In-The-Loop-Simulation (A-MILS) framework has been commissioned to verify and validate the AEDECS performance by adopting advanced modeling techniques using Functional-Mock-up Interface standard. AEDECS closed loop performance studies have been carried out in A-MILS with three heterogeneous, tightly coupled, interdependent subsystem models which are developed using different commercial software packages viz. MATLAB/Simulink based Electronic Controller Model, AMESim based Hydro-Mechanical Plant Model (HMPM) and MATLAB/Simulink based Aero Engine Model. A-MILS provides a real-time simulation platform with MATLAB/Simulink configured as interactive native environment while exploring the possibility of coupling/importing the AMESim based HMPM using FMI standard through data exchange mode as Simulink S-function. AEDECS closed loop performance studies have been demonstrated satisfactorily and the framework has effectively improved AEDECS design process, shortened the development time while addressing the challenges pertaining to interoperability of subsystem models developed in different software packages, coupling of varied fidelity subsystem models with real-time data exchange between these models.

***Index Terms*— AEDECS, A_MILS,A-CILS, FMI, FMU, MATLAB/Simulink, AMESim, HMPM**

I. INTRODUCTION

With recent developments in Modeling & Simulation techniques, a heterogeneous model-based approach has been adopted to commission a collaborative M&S framework. The commissioned M&S framework adopts advanced modeling and simulation techniques using Functional Mock-Up Interface (FMI) standard to resolve multi-domain subsystem models interoperability and model re-usability issues. A model component conforming to FMI standard is referred to as Functional Mock-up Unit (FMU) [1]. A FMU is IP rights compliant and can be imported/exported in two modes, namely Model Exchange and Co-Simulation [2]. The FMI tool for MATLAB®/Simulink offers easy integration of FMUs developed in different domains. The M&S framework has been configured as A-MILS to study open loop and closed loop performance studies of AEDECS while implementing the FMI- model exchange mode.

1. Advanced Modeling Approach using Functional Mock-up Interface

A typical Hydro-Mechanical Plant Model (HMPM) has been developed in AMESim package with necessary input and output signal interfaces. Using FMI-model exchange mode, the modeling environment generates C code of a dynamic HMPM in the form of input/output block that is integrated in to the simulation and modeling tool. The AMESim based HMPM converted to Simulink S-function and is exported to Simulink using AME2SL interface block. AME2SL allows to load the AMESim model into Simulink along with allied files. The imported HMPM is executed in MATLAB/Simulink [3] for both non-real time integrated simulation and also translated to a real-time simulation setup to study real-time effects when integrated with Digital Controller model developed in MATLAB/Simulink having better fidelity. The conceptual block diagram for this process is shown in Figure 1.

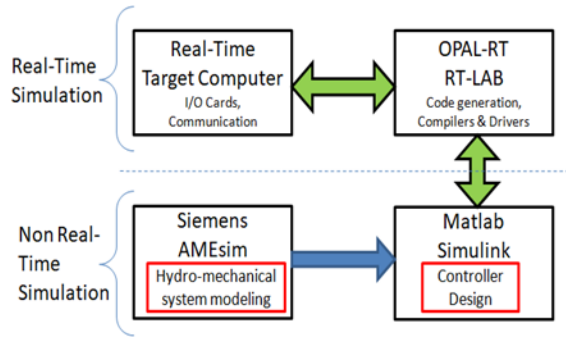

Figure 1: AMESim- Simulink model exchange

The detailed work flow to develop AMESim based model, importing in to MATLAB/Simulink environment and integration with controller model and aero engine model is indicated in Figure 2. The integrated simulation of AEDECS is performed in Simulink to study open loop, closed loop behavior along with fault mode behavior

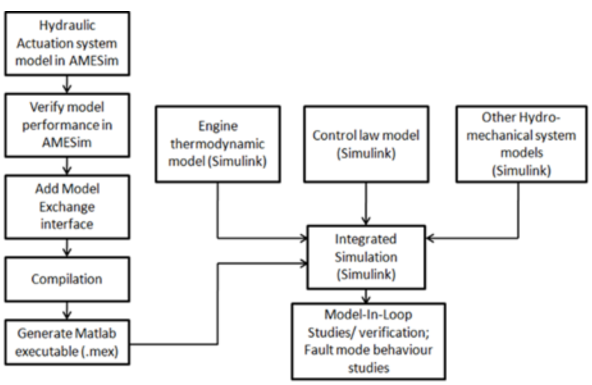

Figure 2: A-MILS workflow with HMPM developed in AMESim package

1.1 AMESim based Hydro-Mechanical Plant Model

AMESim is Advanced Modeling Environment Simulation software extensively used to build physical models [4]. A simplified physical HMPM comprising of Electro –Hydraulic Servo Valve (EHSV) and actuator has been developed in AMESim package. This model is executed using AMESim native solver 'Regular'. Further the Model is converted to S-function using AME2SL interface block and exported to MATLAB/Simulink with FMI Toolbox for MATLAB/Simulink for A-MILS operation. Figure 3 indicates the AMESim based HMPM and the HMPM parameters are indicated in Table I.

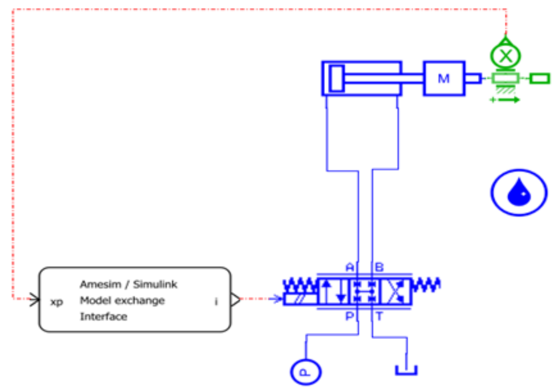

Figure 3: Simplified HMPM with AME2SL interface block

II. ADVANCED-MODEL-IN-LOOP-SIMULATION FRAMEWORK

A real-time Collaborative Framework built around OPAL-RT configured as A-MILS is indicated in Figure 4 with in-house developed GUI as indicated in Figure 5 to monitor the open loop and closed loop performance of the AEDECS. A-MILS set up can be operated in three modes namely, Configure, Manual mode and Simulation mode. The hardware and software configuration is indicated in table I.

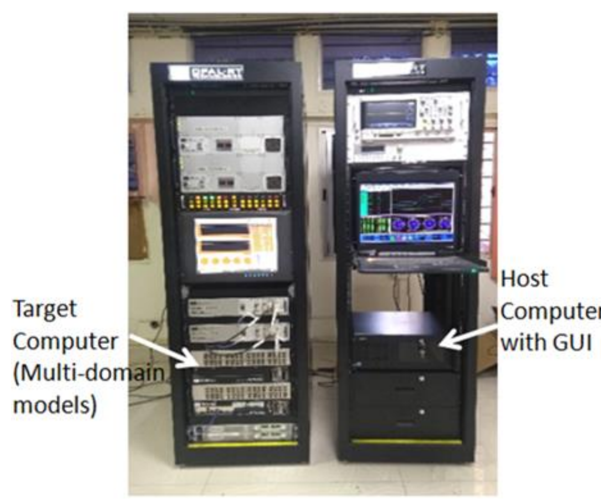

Figure 4: A-MILS Framework

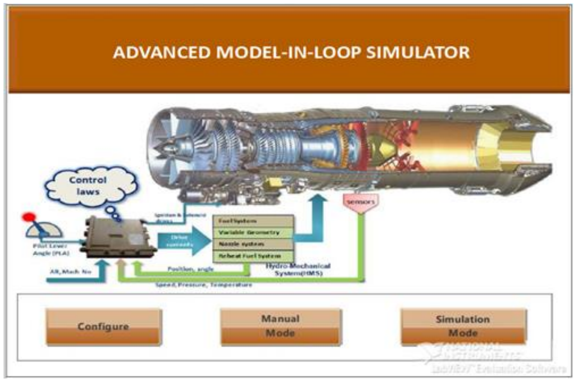

Figure 5: GUI for A-MILS & A-CILS

TABLE 1: AEDECS Subsystem Models parameters

AEDECS Subsystem	Parameter Details
1. AMESim based HMPM a) Electro-Hydraulic servo Valve	AMESim version 2012.1 HSV34_08 is a submodel of a 3 position 4 port hydraulic center AT
b) Actuator Model	Actuator stroke length: 50mm Initial displacement: 10mm Total load: 100kg Dead volume at port end: 110mm^3 Dead volume at port end: 210mm^3 Rod angle with horizontal: 0 deg
	Integrator type: Standard Print interval: 0.1 s Simulation mode: Dynamic Solver type: Regular Error type mixed with tolerance: 1e-5.
2. Controller (MATLAB/ Simulink) Model	Type: Proportional + Integral Solver: Fixed step ODE 3 Sampling time: 1 ms
3. Target Computer Configuration	OPAL-RT, OP650 Target Compiler : Microsoft Visual C++ 2013 Professional

A typical position control loop with the Digital Electronic Controller (DEC) has been implemented in MATLAB®/Simulink as a simple proportional controller and the AMESim based HMPM is imported into MATLAB®/Simulink as s-function. The closed loop simulation has been performed in native MATLAB®/Simulink. Figure 6 shows the closed loop position control loop. Figure 7, Figure 8 and Figure 9 indicate the plant states, position control loop in native MATLAB®/Simulink and step response plot respectively monitored during the simulation.

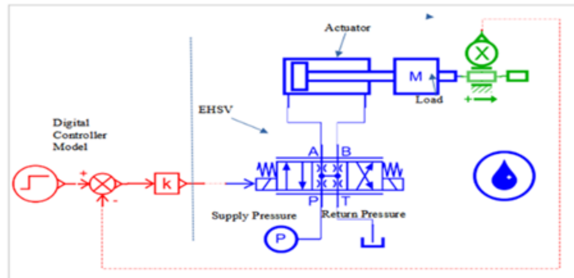

Figure 6: Position Control loop using FMI-Model exchange in A-MILS

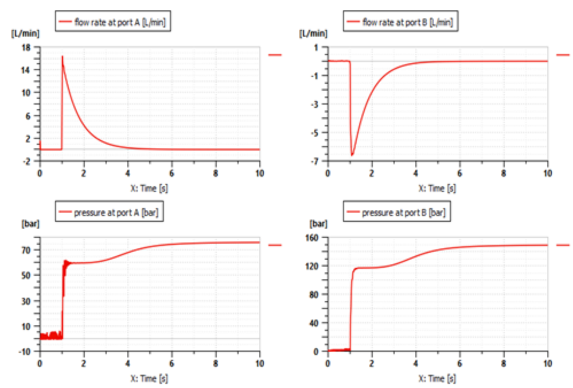

Figure 7: Plant States-AMEsim

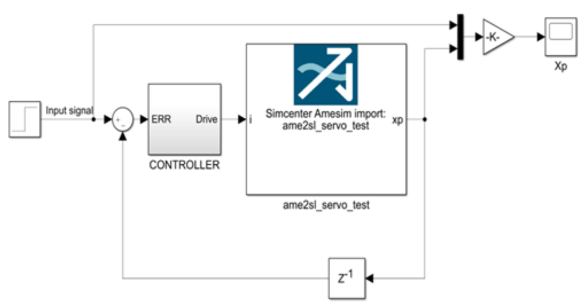

Figure 8: Position Control Loop in MATLAB/Simulink native environment

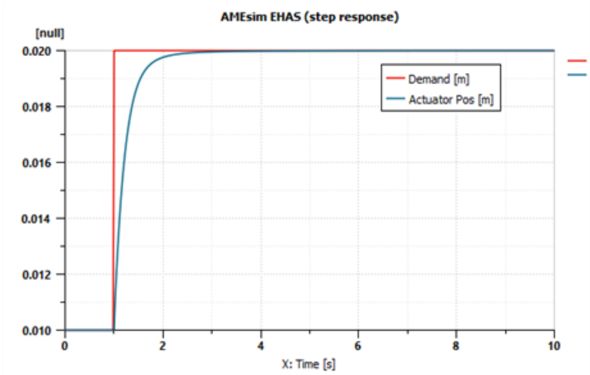

Figure 9: Step response of HMPM

III. AEDECS CLOSED LOOP PERFORMANCE STUDIES AS PART OF A-MILS FRAMEWORK

In this section all the three subsystem models of AEDECS are configured to run in closed loop. In particular, a HMPM (combination of typical EHSV model + Hydraulic actuator model) has been developed in AMESim software while the aero engine model and the Digital controller model are developed in MATLAB/Simulink. A-MILS framework for AEDECS is indicated in Figure 10. Figure 11 indicates integrated simulation of AEDECS with AMESim based HMPM integrated with other two subsystem models and figure 12 shows critical engine model, HMPM parameters for 5% step demand in engine speed.

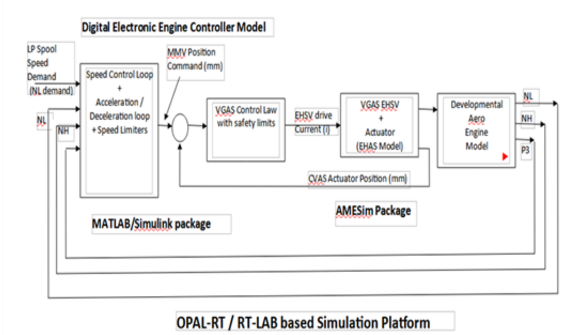

Figure 10: AEDECS A-MILS Framework

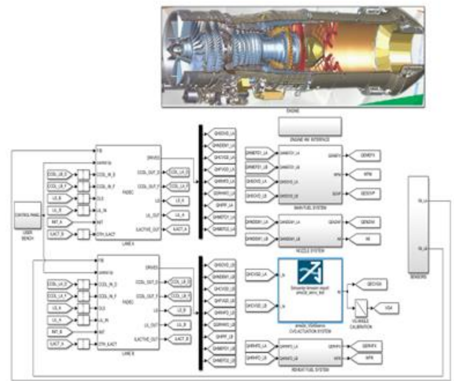

Figure 11: AMESim based HMPM integrated with Aero Engine Model in Simulink and DECU Model in Simulink.

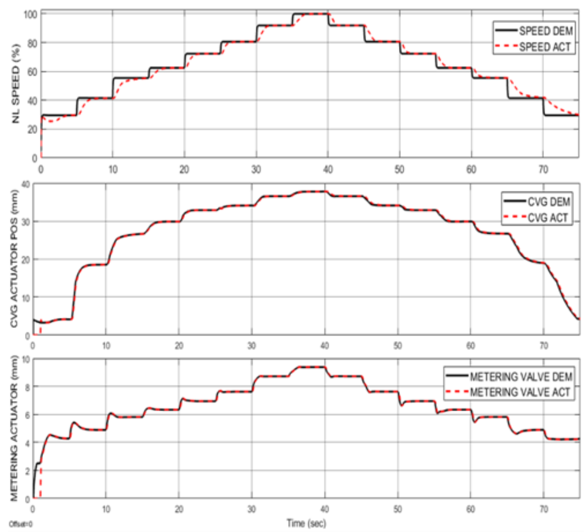

Figure 12: Results of Integrated simulation using HMPM AMESim model exchange

- Analysis of Results

AMESim model is exported to Simulink as an s-function through model exchange. The Integrated simulation con-sists of an Engine model executing with 1ms step, a Dual lane Controller model executing in 20ms, and Hydro-mechanical system model exported from AMEsim execut-ing in 10us step size. Figure 12 shows the result of the in-tegrated simulation model. Response of engine spool speeds are shown. For simulation purpose a step of 5% in spool speeds is input and the output is recorded. Spool speed exhibit a time constant of 1-1.5 sec which is a repre-sentative dynamics for the class of engine described. The actuators (HMPM) responses, particularly of the CVG actu-ation system is shown, which is imported from AMESim to Simulink. Main engine fuel control Hydro-mechanical sys-tem response is also shown for completeness. CVG actua-tion system shows a time constant of 200ms which is a rep-resentative of a class of actuation system considered.

CONCLUSION

Despite the significant advances in modelling, simulation, design and virtual testing, there is still a lack of integrated framework enabling multi-domain modelling and simulation. The paper discusses on integrating heterogeneous subsystem models of a typical AEDECS via FMI standard. A-MILS framework has been commissioned. The simulation shows the capability of the framework to integrate multi-tool models to leverage specialist capabilities of domain specific simulation tools. This has resulted in a rich integrated simulation, which can be effectively used for study of failure mode effects on the total system performance. This multi-tool models can be extended for all of the components for a further enhanced simulation. Use of Multi-tool compatible FMI standards are the obvious next extension of this framework, wherein the exchange protocols are more formally defined at the application tool level.

ACKNOWLEDGEMENT

The authors are thankful to Director, GTRE for giving permission to publish this paper.

REFERENCES

[1] T. Blochwitz et.al, Functional Mock-up Interface 2.0: The standard for Tool independent Exchange of Simulation Models, , Proceedings of the 9th International Modelica Conference, Sept 33-5,2012,Munich, German

[2] Jenny Malig et.al, Recent Advances in Shared Simulation Approaches in Systems Engineering Processes, , TWT GmbH Science & Innovation, Ernsthaldenstrasse 17, 70565 Stuttgart, Germany.

[3] Gerald Schweigwer et.al, An Empirical Survey on Co-simulation: Promising Standards, Challenges and Research Needs, Delphi study, Jan 2019.

[4] Bin Li et.al, Design and Simulation of Electro-hydraulic Control Valve based on AMESim, Journal of Physics, 2137 (2021) 012006, doi:10.1088/1742-6596/2137/1/012006.