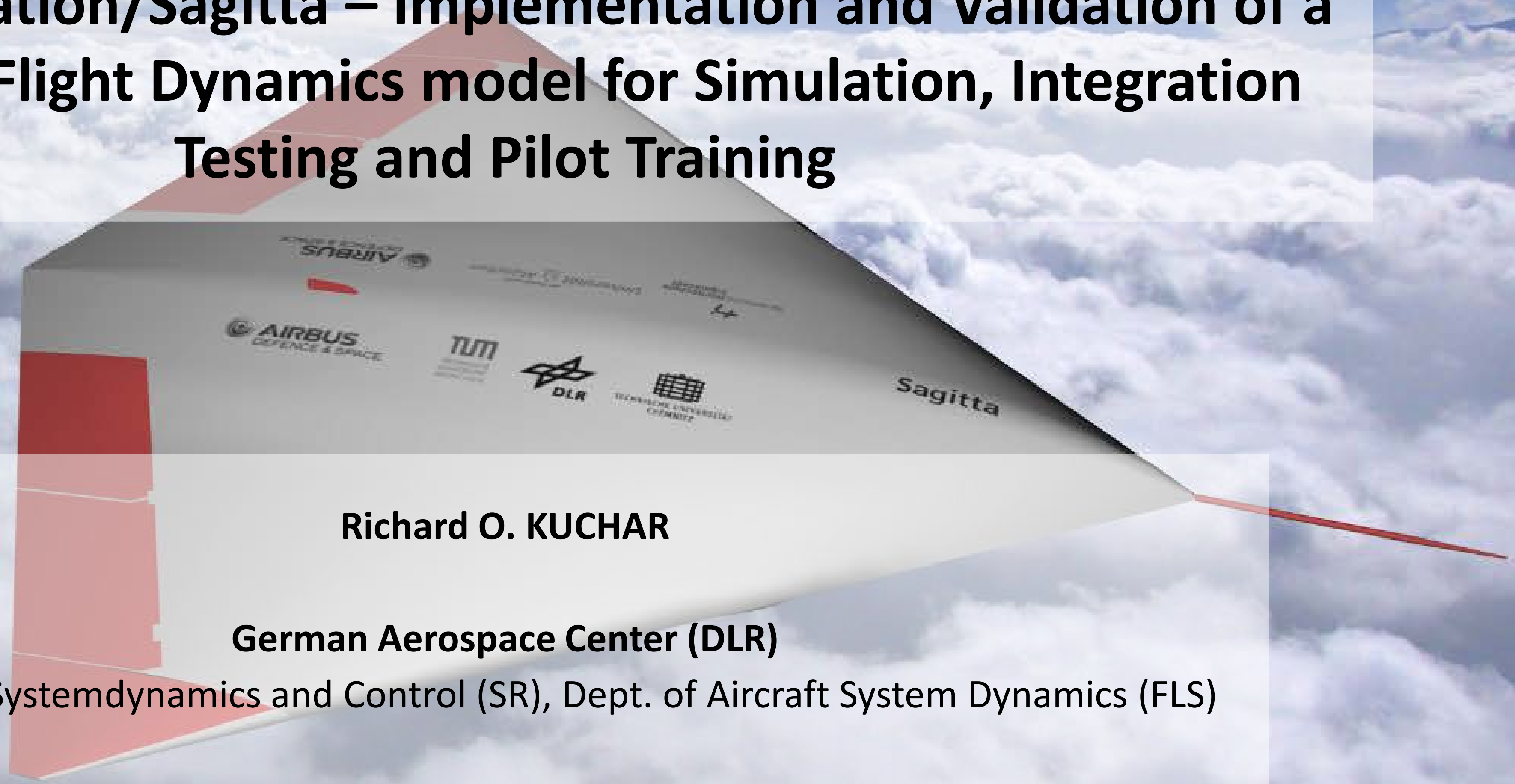
Open Innovation/Sagitta – Implementation and Validation of a Real-Time Flight Dynamics model for Simulation, Integration Testing and Pilot Training



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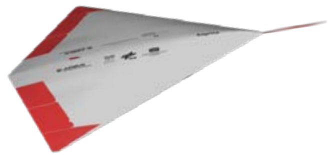
ASIM 2017
Ulm, 09.03.2017

DLR



Outline

- Introduction to the OpenInnovation/Sagitta project

- **Introduction to the Sagitta Simulation and Integration Testing (SIT) environment**

- **Flight Dynamics Model (FDM) implementation**
  - Modelica Flight Dynamics Library
  - Integration of Sub-Components:
    - Mass model
    - Aerodynamic model (ADM)
    - Propulsion (PROP) model – (similar Actuator (ACT) model integration)
  - Assembly of the Sagitta SIT Flight Dynamics model

- **Sagitta SIT FDM Validation measures**

- **SIT in-use videos**

- Conclusion and Outlook

Sagitta – Airbus Defence and Space Open Innovation
UAV Technology Scouting Initiative

Research Program

Field of Technology:

- Mission Management
- Flight Control Systems
- Platform and overall system design
- Communication system
- **Rapid Control Prototyping of Flight Control Laws**
- Propulsion & Energy Generation System
- Modular Payload System

AIRBUS DEFENCE & SPACE

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

EADS INNOVATION WORKS

Technische Hochschule Ingolstadt

Collaborate to Innovate !

Universität der Bundeswehr München

TECHNISCHE UNIVERSITÄT CHEMNITZ

IAS TUM Institute for Advanced Study

TUM Technische Universität München

Research Demonstrator

Sagitta:

- Dimensions ~3 x 3 m
- Max. Speed ~80 m/s
- Radius of Action ~20km
- Max. Flight Time ~1h

Our task in the scope of the Demonstrator A/C (Requirements for SIT)

Simulation and Integration Testing Setup:

- One setup for simulation and integration testing activities – forming a “virtual aircraft”
- “Step-by-step” replacement of software models with available hardware – controlled via patch panel
- Simulation models resemble identical ICD, as original flight H/W
- Scriptable / automated simulation and test execution
- Real-time capable system, with defined maximum latencies (along H/W measurements)
- Fault insertion capabilities …

… used for:

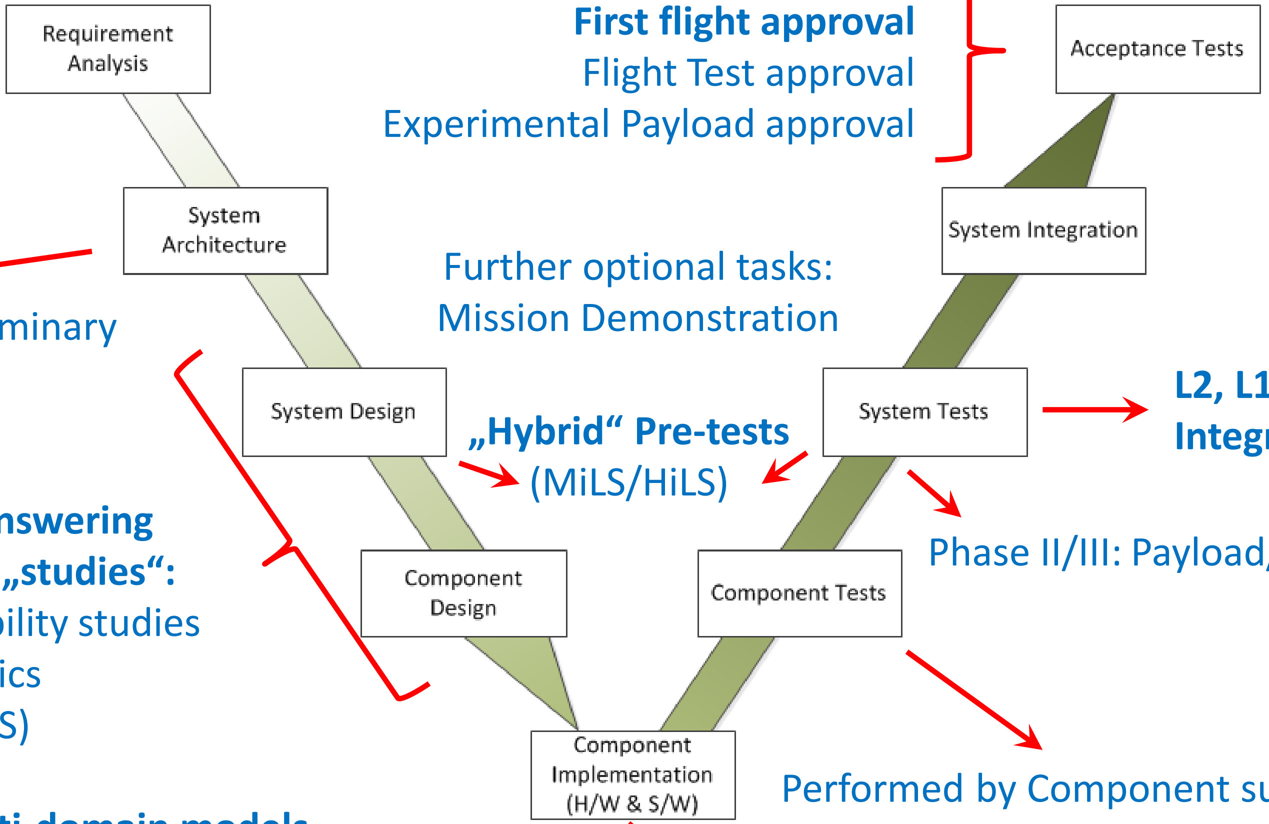
- Simulation Studies for early design evaluation (e.g. Manual Landing Study, Taxi Tests, …)
- Integration Testing (from component level – fully assembled aircraft, “hybrid setups”, V-model)
- Formal First Flight Qualification of Aircraft and Equipment
- External Pilot Training for maiden flight

→ Basic Model Setup:

- Modelica based Flight Dynamics Model (integrated via Functional Mockup Interface)
- Simulink component models (integrated via Simulink Coder)

Overall development process – Simulation/I&T interaction

EP Training (ARINC610C functionality)
First flight approval
Flight Test approval
Experimental Payload approval



Early Prototyping
→ based on early/preliminary datasets

Further optional tasks:
Mission Demonstration

„Hybrid" Pre-tests
(MiLS/HiLS)

L2, L1 and L0 Integration Tests

Phase II/III: Payload/Experiments integration tests

Development Simulation - Answering engineering questions – e.g. „studies":

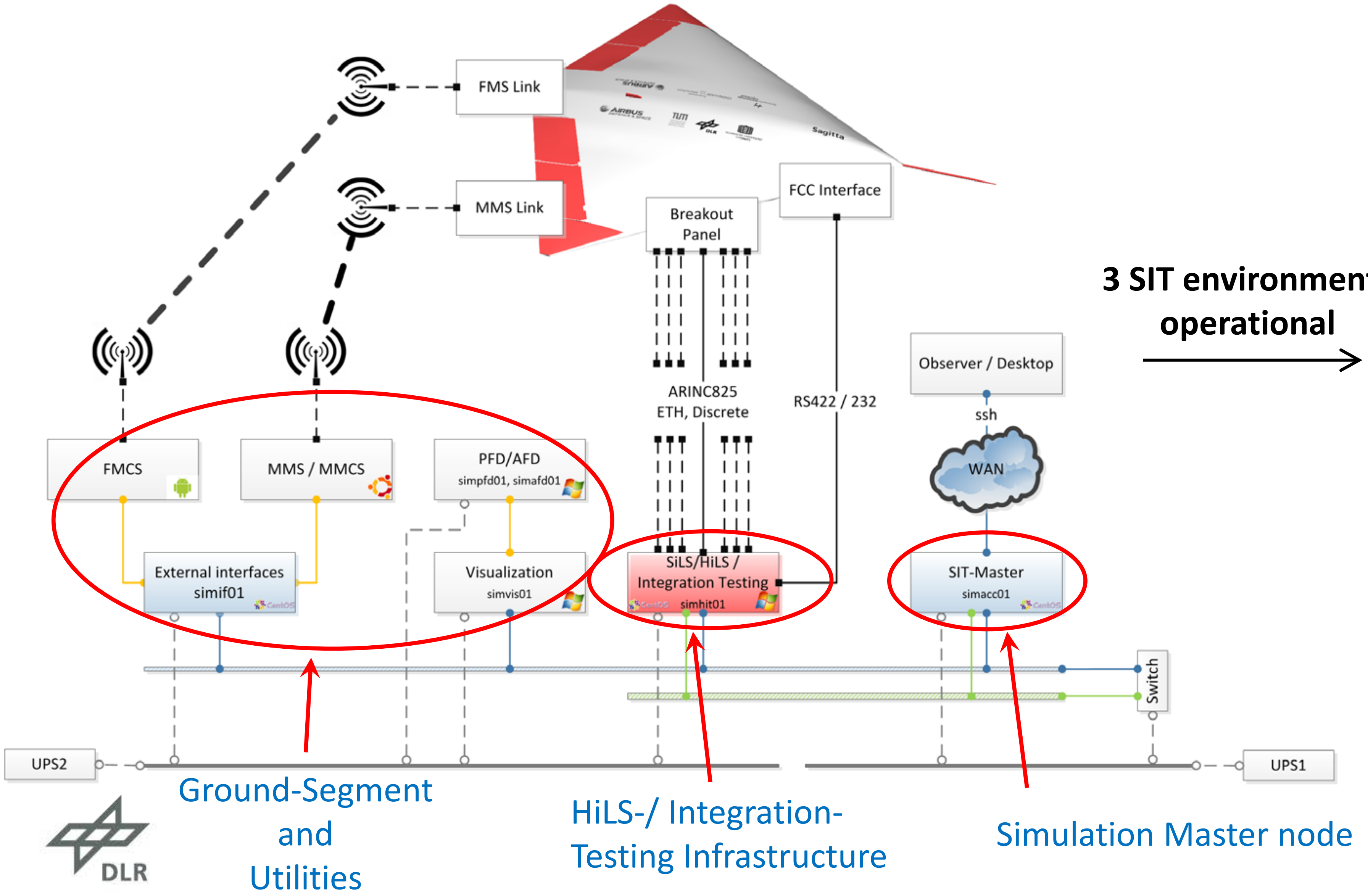
- Various component feasibility studies
- Landing Gear characteristics
- Landability study (e.g. MLS)
- Handling qualities (EP)

→ based on preliminary multi-domain models

Performed by Component supplier

Implementation of "final" FDM

Architecture and Implementation of the Sagitta Simulations- und Integration Testing environment (SIT)



3 SIT environments operational

SIT #2: FMS Rig @ TUM Lab

Software for Simulation and Integration Testing

MiLS – Airbus DS SIRIUS:

- Execution of models based on AP2633 and ARINC653 standards
- Source code in ANSI C/C++/ADA direct embeddable, C++/C# etc. require wrapper functions + runtime
- SIRIUS SDK for directly embedding SIRIUS functionality in model code (e.g. network sockets, shared memory, timers, …)
- Utility functions: “SIRIUS Workbench” (Eclipse RCP based) and “SIRIUS Web interface” – simulation control, Scripting interface (Groovy, Python), “Record”/“Replay”, …

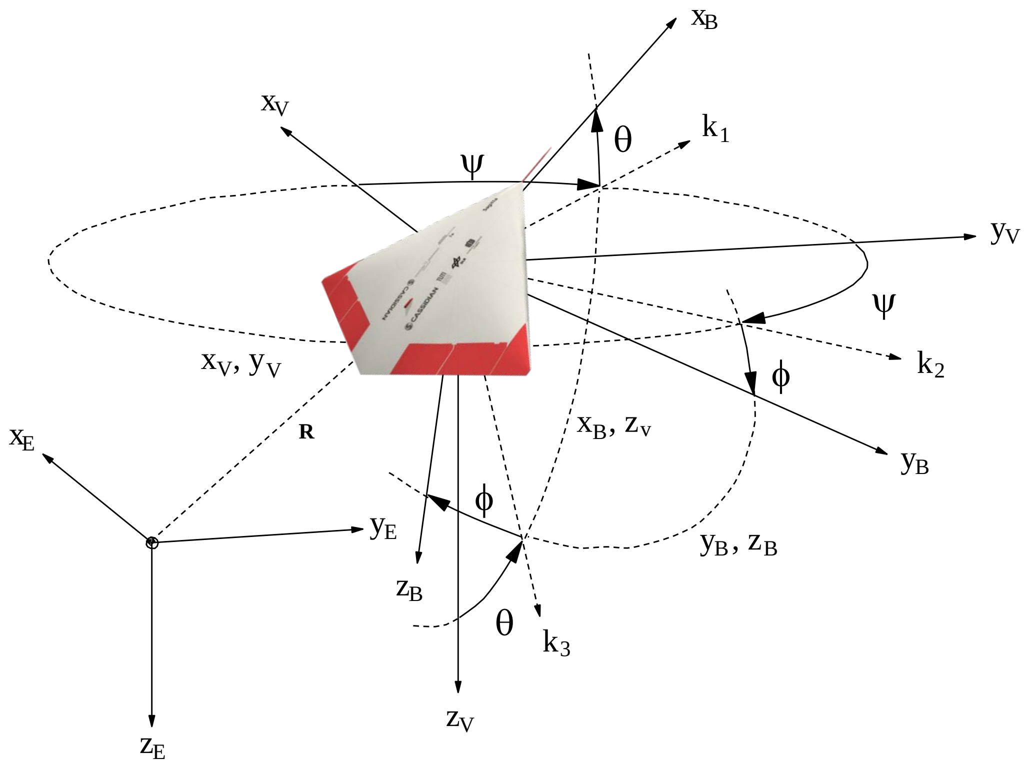
HiLS/IT – Airbus DS AIDASS:

- Supports multiple I/O interface boards via PCIe: RS232/422, Ethernet, CAN/ARINC825, Discrete, MILBUS and many more
- On- and Offline Data analysis – “Record” and “Replay”, Script, Real-time scripting and User-Program capabilities for test case execution
- Signal generator for specific test signal generation

→ Interfacing AIDASS with SIRIUS via TssGateway Service (Interprocess Communication, performance critical)

– The Sagitta Demonstrator FLIGHT DYNAMICS MODEL –

Flight dynamics – 6DOF Equations of motion



- Simplified equations of motion:
  - Forces:

$$\begin{pmatrix} \boxed{\begin{matrix} X_{aero} \\ Y_{aero} \\ Z_{aero} \end{matrix}} + \boxed{\begin{matrix} T_x \\ T_y \\ T_z \end{matrix}} + \boxed{\begin{matrix} X_{ldg} \\ Y_{ldg} \\ Z_{ldg} \end{matrix}} \end{pmatrix} = \boxed{m} \begin{pmatrix} \dot{u} + qw - rv + g_0 \sin\Theta \\ \dot{v} + ru - pw - g_0 \cos\Theta \sin\Phi \\ \dot{w} + pv - qu - g_0 \cos\Theta \cos\Phi \end{pmatrix}$$

  - and Moments (w/o contributions by propulsion and systems)

$$\begin{pmatrix} L \\ M \\ N \end{pmatrix} = \begin{pmatrix} I_x \dot{p} + (I_z - I_y) qr \\ I_y \dot{q} + (I_x - I_z) rp \\ I_z \dot{r} + (I_y - I_x) pq \end{pmatrix}$$

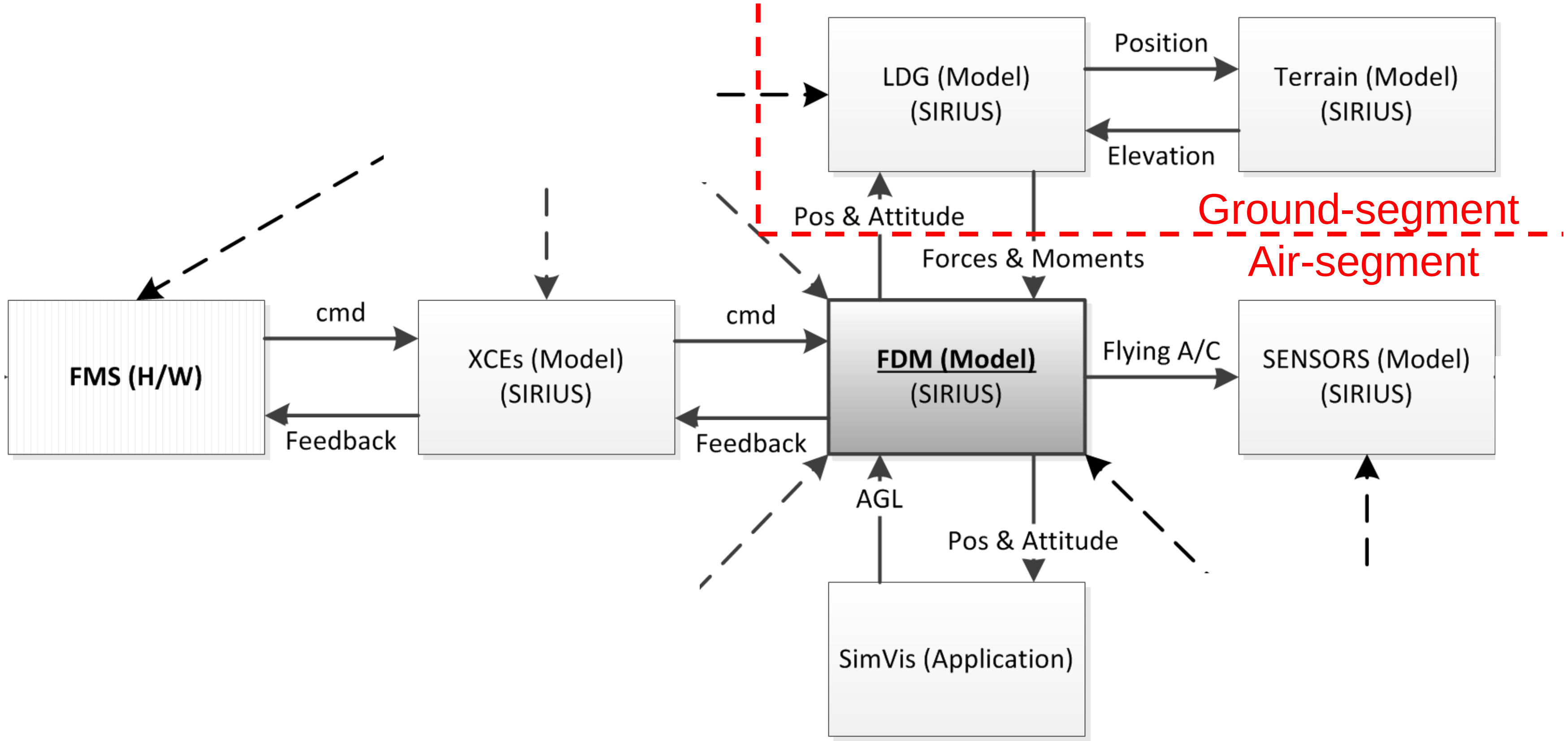
With:

p,q,r … Angular velocity in body frame

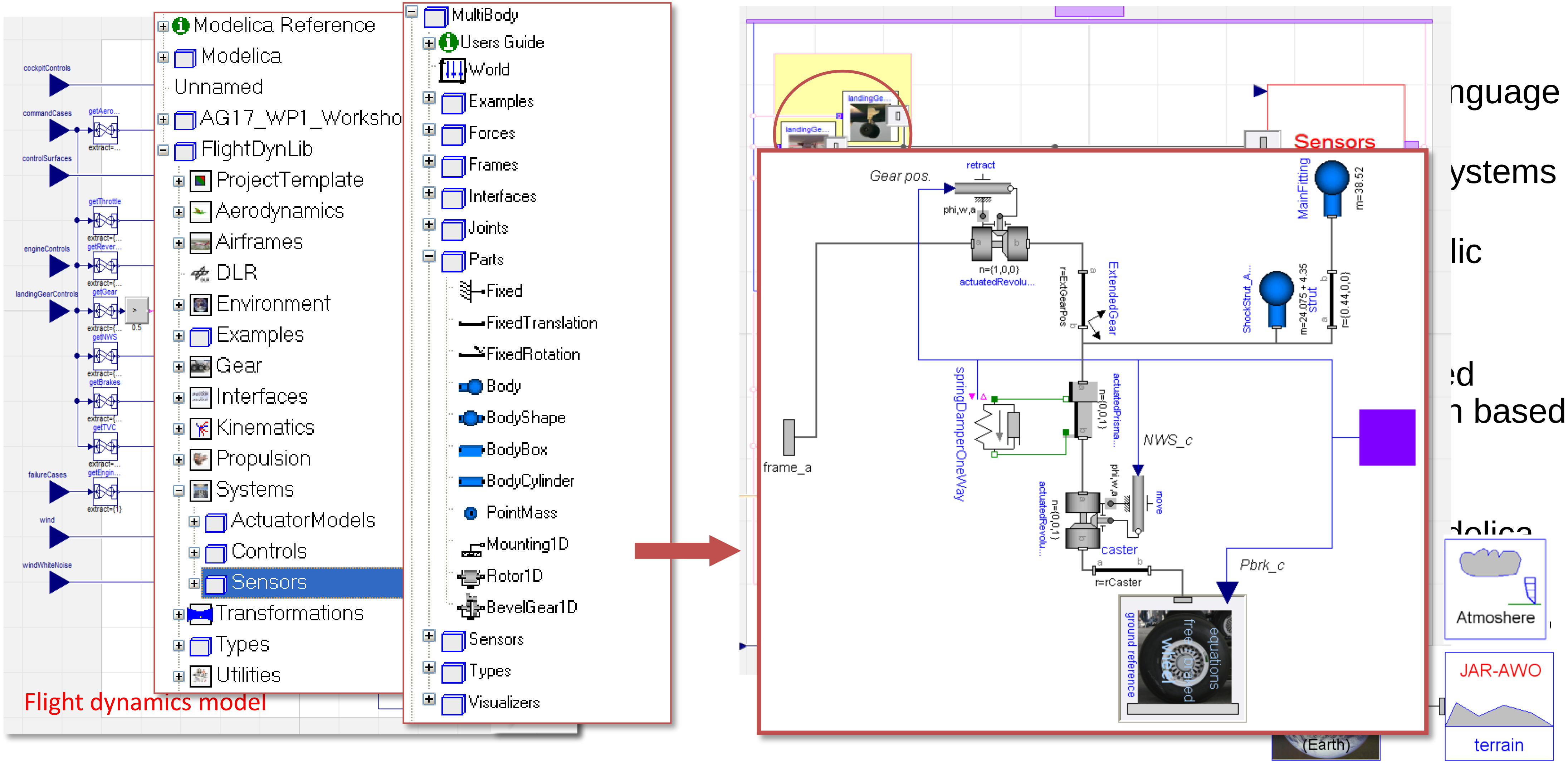
u,v,w …Velocity of A/C in body frame

Φ,Θ ... Euler angles

Sagitta SIT model interaction – FDM



DLR-SR Flight Dynamics Library



FDM Sub-Components – I

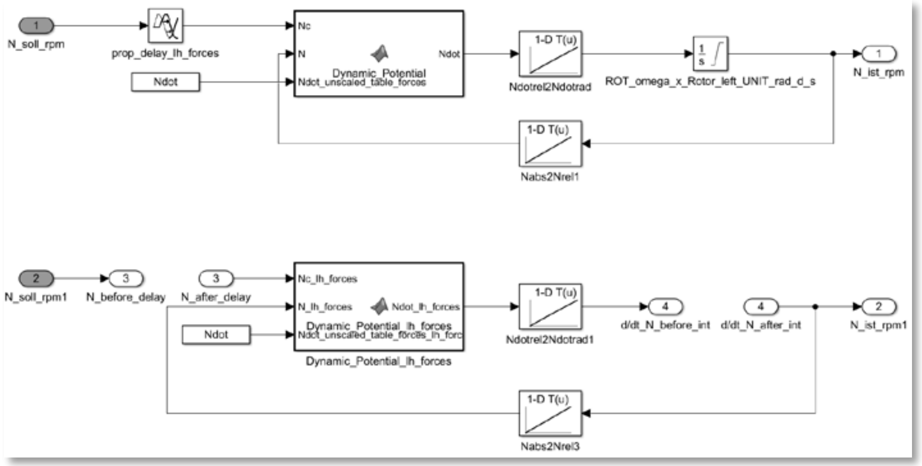
- **Aerodynamic Data Module (ADM)** – provided by TUM-AER/THI:
  - Derived from wind tunnel data and CFD results (dynamic derivatives, consolidation)
  - Originally provided via Matlab script

  - Reworked into vectorized interpolation scheme, ANSI C-code
  - Integration into Modelica FDM framework:

```
function Stat_noVT_CX_

input Real alpha[1];
input Real beta[1];
output Real Stat_noVT_CX_Aero_A_B;

external"C" Stat_noVT_CX_Aero_A_B =
    Stat_noVT_CX_(alpha, beta);

annotation (Include="#include \"
    SagittaADM_ph03v02.c\"");
end Stat_noVT_CX_;
```

- **Propulsion model (PROP) – I** – provided by TUM-LLS:
  - Derived from test bench data (static and dynamic thrust and CFD results (intake)
  - Originally provided as Simulink model

  - Integration into Modelica FDM framework:
    - Extract all dynamic content (delays, integrators, …) from the model



FDM Sub-Components – II

Propulsion model (PROP) – II

- Export model via Simulink Coder without continous states:

```
function ENG_MOD_Coder_InitModel_

external"C" ENG_MOD_Coder_InitModel_();

annotation (Include="#include \"
    ENG_MOD_Coder.c\"");
end ENG_MOD_Coder_InitModel_;
```

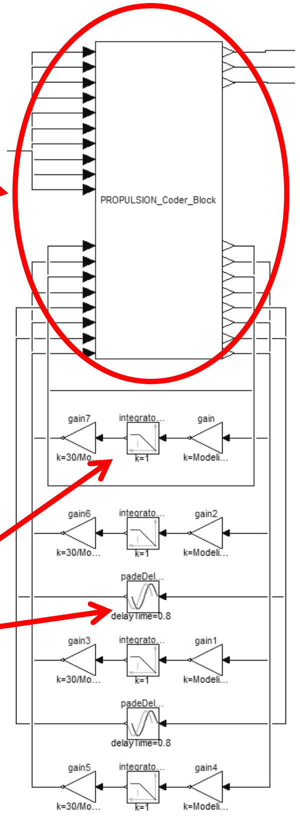
```
function ENG_MOD_Coder_OneStep_

input Real[18] dU;
output Real[26] dY;

external"C" ENG_MOD_Coder_OneStep_(dU, dY);

annotation (Include="#include \"
    ENG_MOD_Coder.c\"");
end ENG_MOD_Coder_OneStep_;
```

- Integration of coded PROP model into the Modelica context:

Simulink model embedded in Modelica

Simulink Coder generated function calls

Re-established dynamic content of the original S/L model in Modelica (e.g. Transport Delay, Integrator, …)



… similar to Actuator model integration

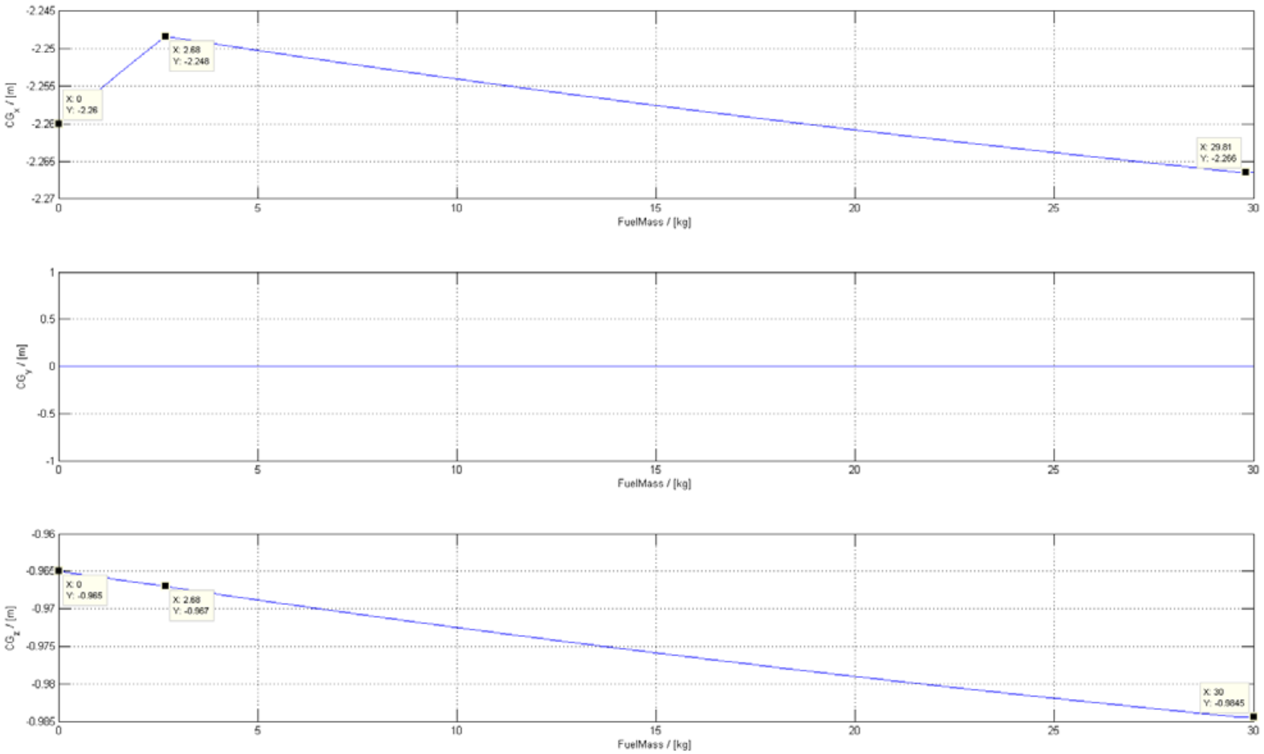
FDM Sub-Components – III

<u>Mass/Weight-and-Balance (WaB) model</u>

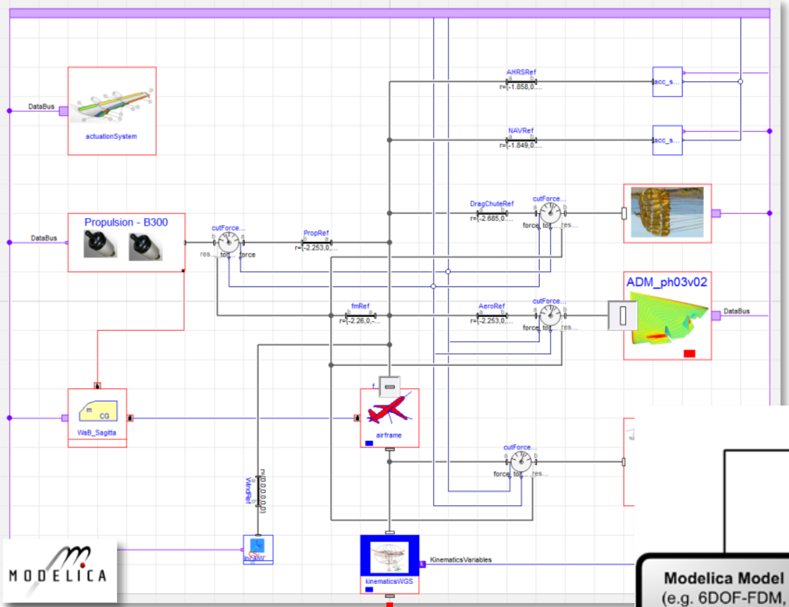
- Covers all variations of:
    - Center of Gravity (CoG)
    - Inertia

  due to Mass-changes / Fuel Flow

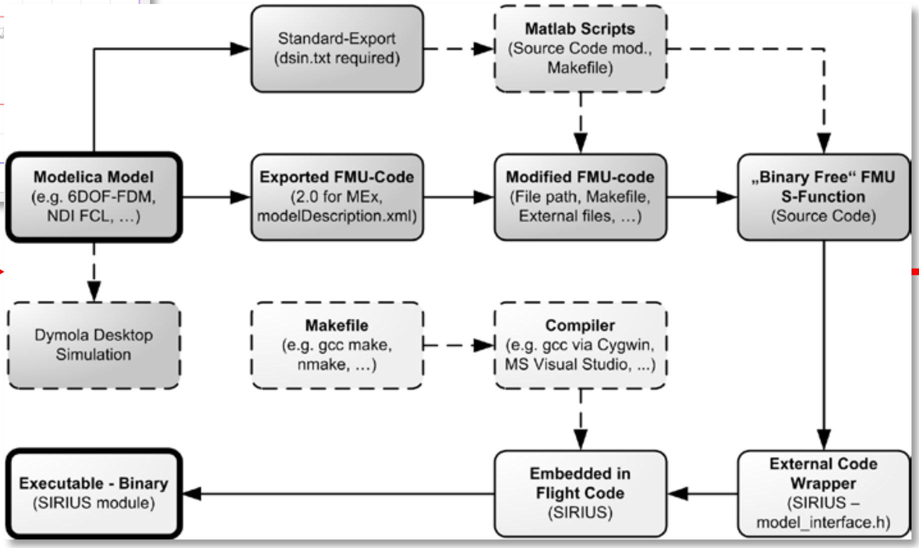
- Therefore WaB and PROP are interacting via Fuel Integrator
- Tank system consists of Main tank and hopper tank – therefore causing nonlinear WaB characteristics

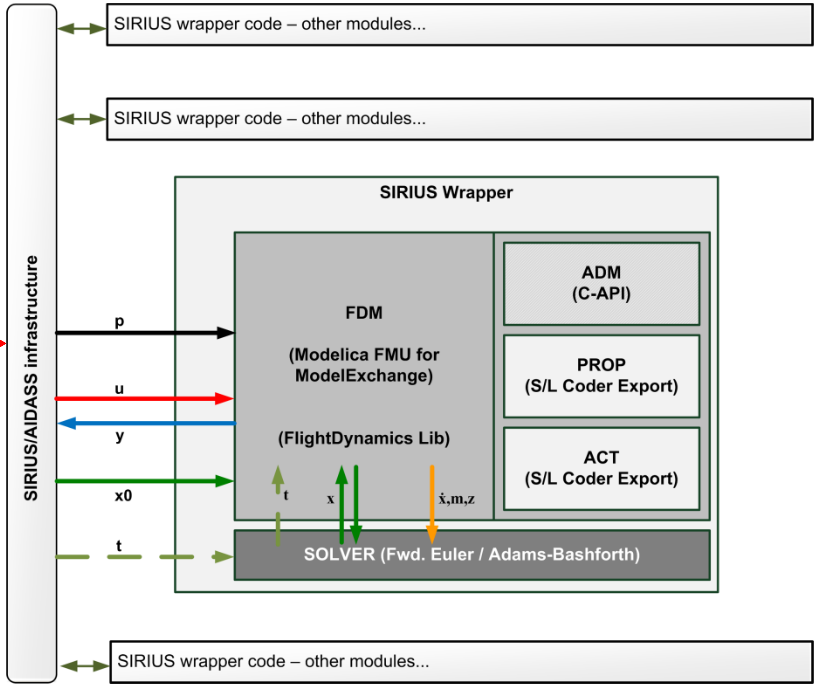


Assembled Flight Dynamics model and Integration in SIRIUS



Model Export via FMI



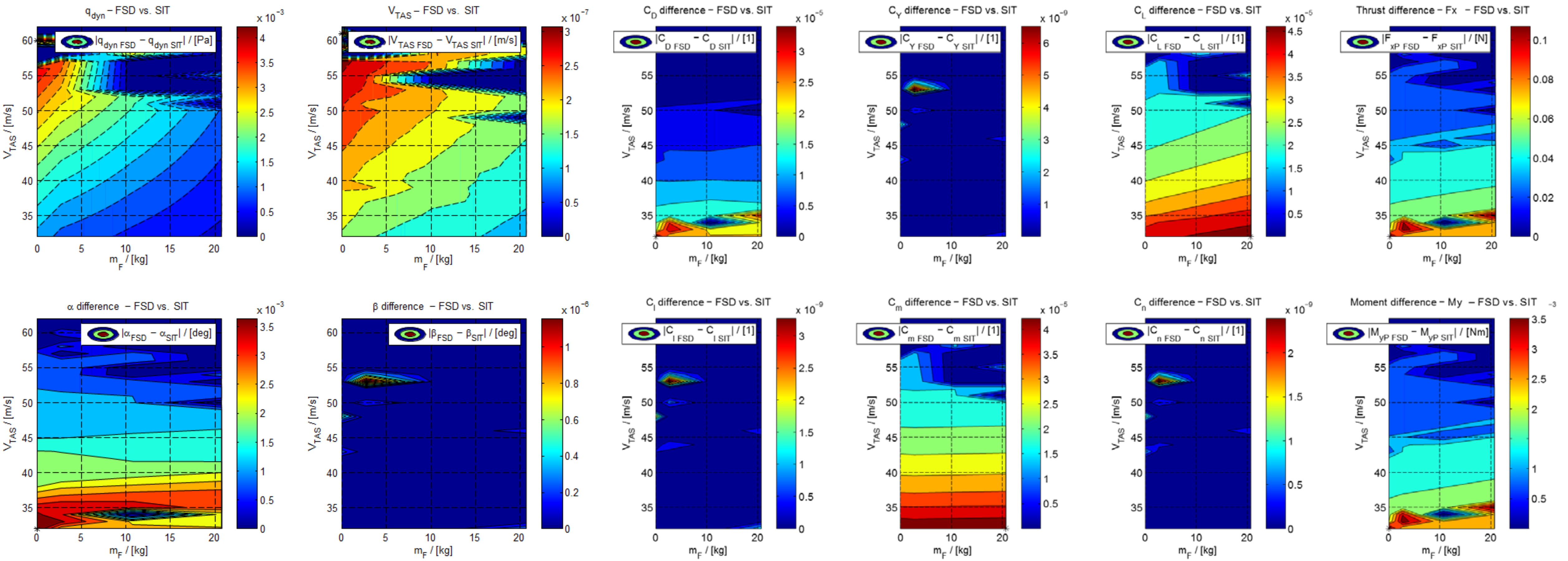


FMI is a standardized interface for the integration of exported Modelica models (ANSI-C code) with various simulation frameworks and platforms – without platform & proprietary dependencies

→ ModelExchange Version utilized for FDM

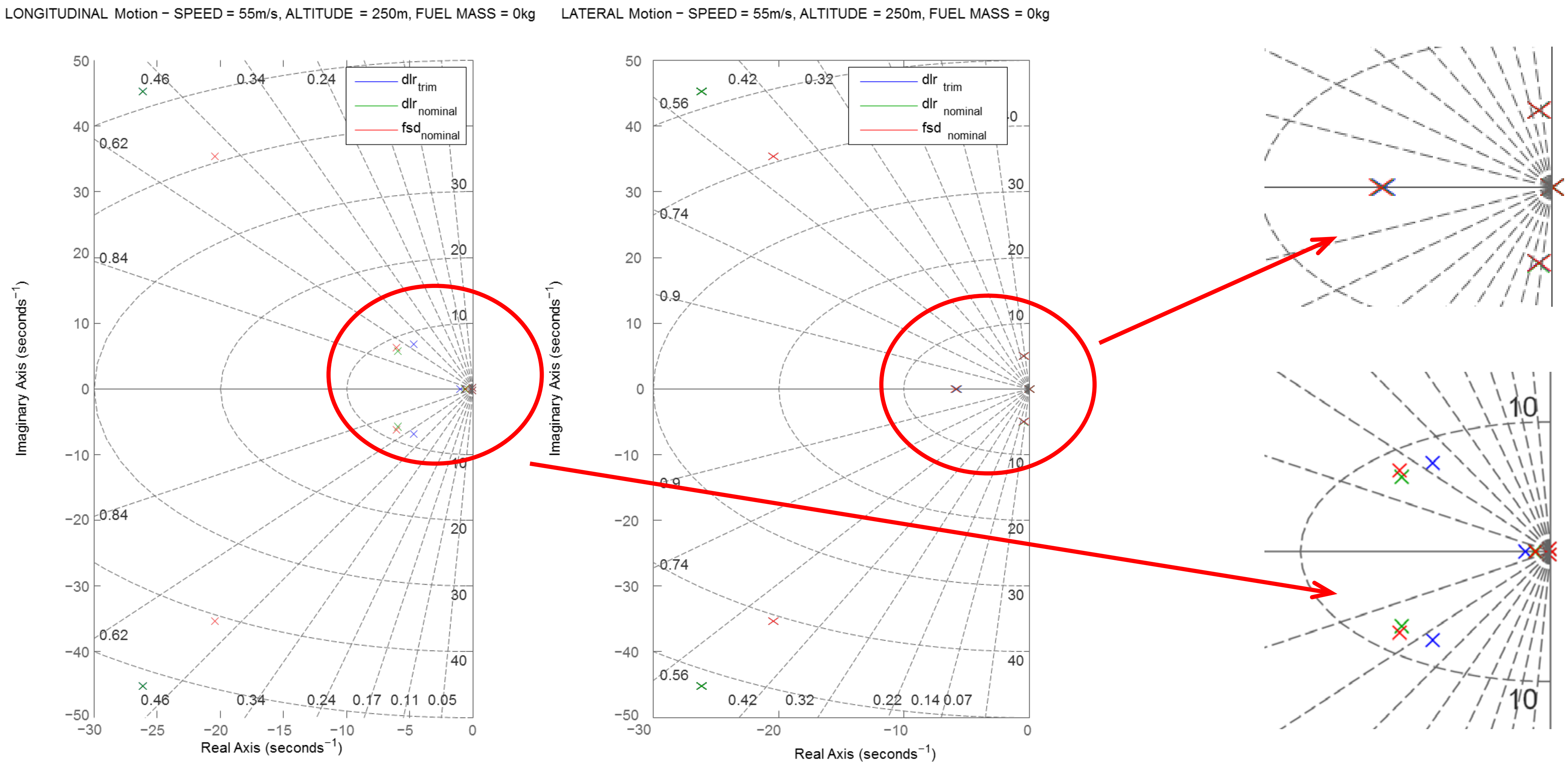
FDM Validation – Stationary comparison

- **Comparison based on dissimilar development of FDM: DLR-SR SIT vs. TUM-FSD FCL Synthesis models**
- 240 trim cases compared (Air-speed, mass and altitude variations)

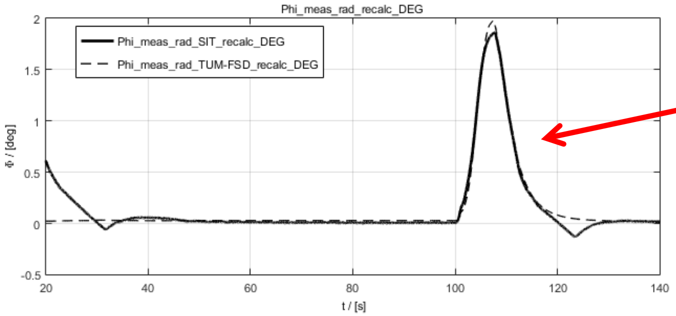


FDM Validation – Linearized Model comparison

- Linearized models have been derived for each of the 240 trim points and compared

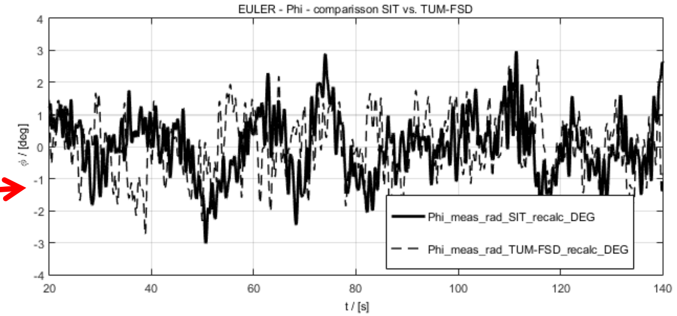


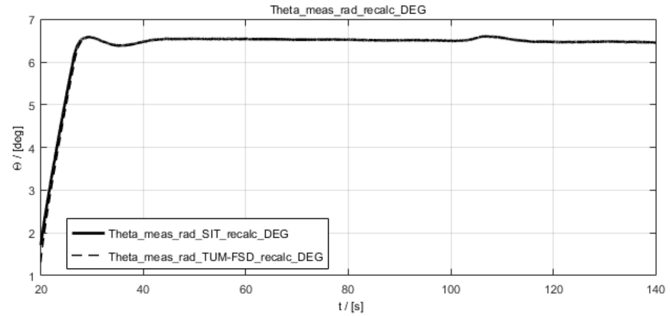
FDM Validation – Mission comparison examples



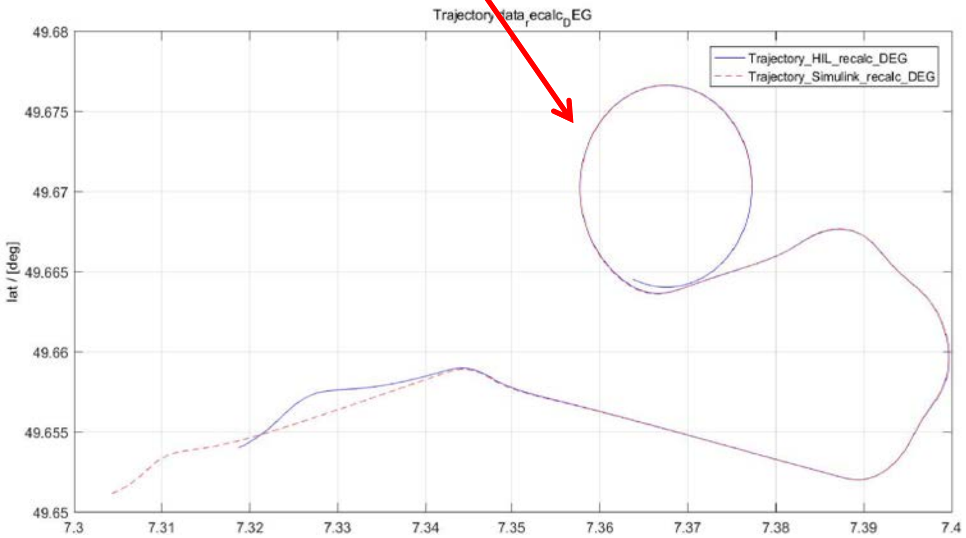
Lateral gust (1-cos, due to MIL-F-8785C)

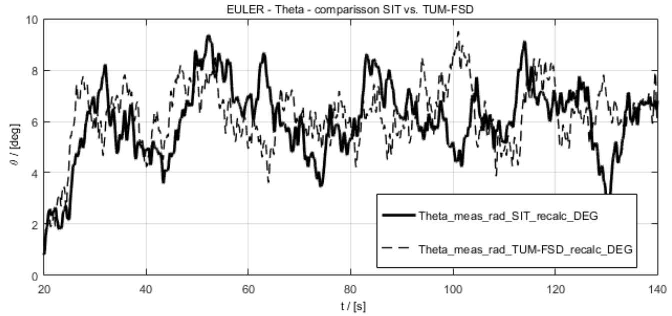
Dryden-Turbulence (due to MIL-F-8785C)

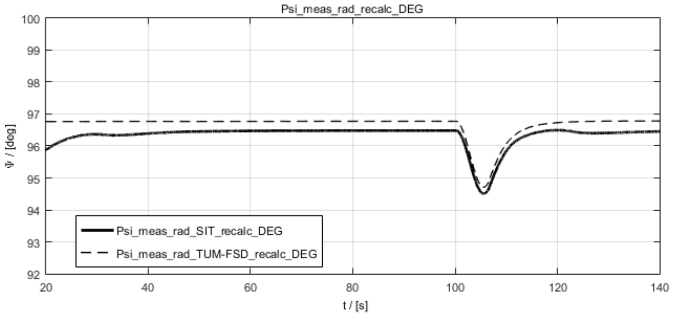


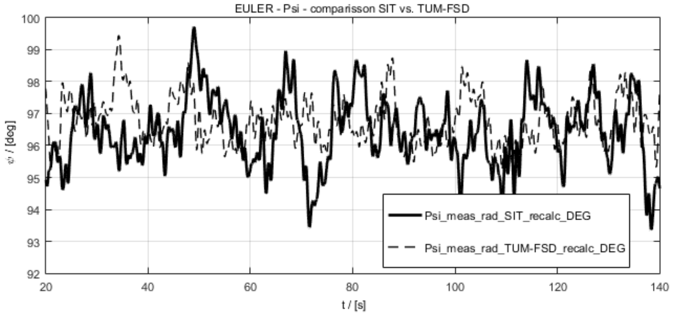


Trajectory follow









→ Small deviations allowed and unavoidable: E.g. different model approach, H/W environment (SIT) vs. all simulated

Videos – L0 SIT Trials (07.03.2017)

L0 SIT Setup

Landing

Take-off

Conclusion and Outlook

- **A flexible and versatile Simulation and Integration Testing environment has been implemented and is intensively used**
- **Core element is the Flight Dynamics model** – receiving commands from FCC and stimulating the SENSOR models – thus closing the loop
- **Major challenge: Define and integrate the respective Sub-Component models (ADM, Propulsion and Actuation) in order to integrate smoothly with the FDM**

- **Lessons learnt: Basic Time Frame of SIT preparations should be in ADVANCE of general implementation activities** – if and where possible!
  - **Incremental build-up of flight-dynamics and component models** in order to keep complexity manageable, when high-fidelity sub-models arise.
  - **Stabilization of SIT implementation activities early on**, then follow on with documented and tested “small, incremental” steps
  - **Validation of models is time consuming, but a core necessity!**

- **Currently intensive testing on all system levels is underway in advance of the Sagitta Maiden Flight**

Thank you for your attention!
Questions?

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