Eric THOMAS
Dassault Aviation

20 + 5 mn

16th Modelica & fmi Conference

Bridging the gap between System Engineering and Simulation, applied to collaborative design of Aircraft Systems

Lucerne, Switzerland
September 8 -10

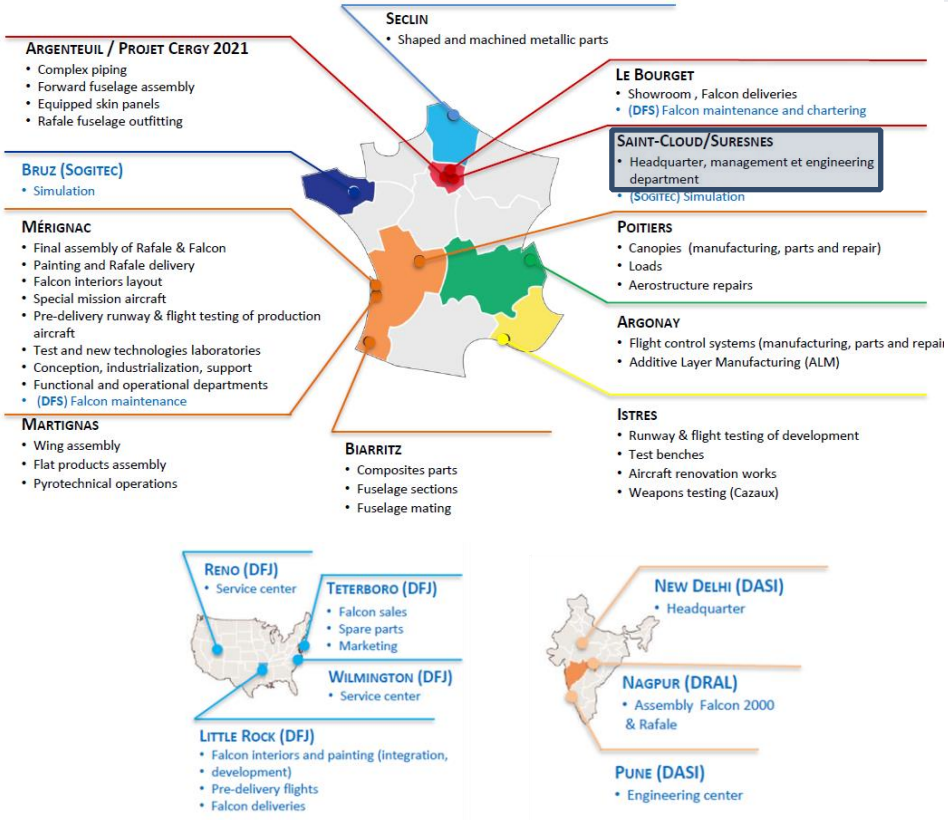
AGENDA

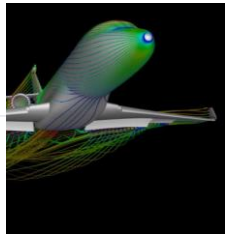
Agenda

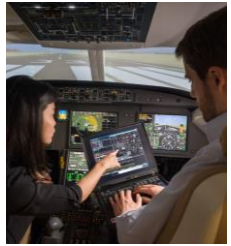
- Context
- Enablers
- Status
- Conclusions and Outlooks

DASSAULT AVIATION

DASSAULT AVIATION







DASSAULT AVIATION

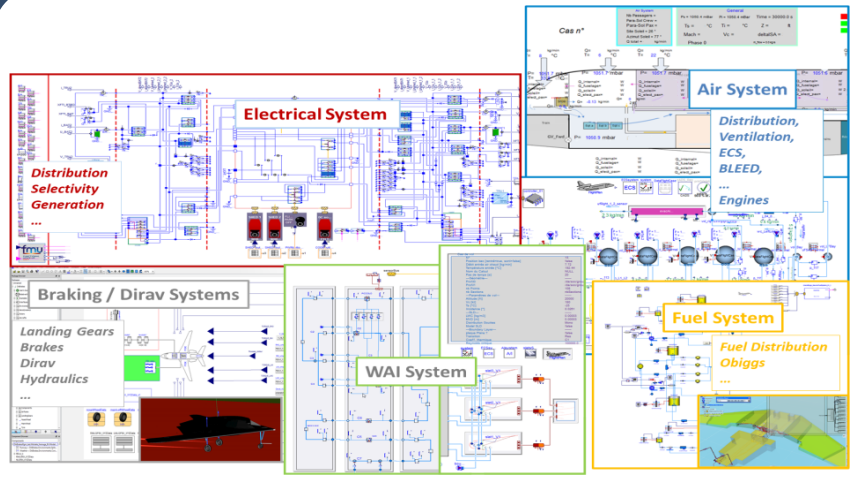
COMPLEXITY ?

IN SYSTEM ENGINEERING AND FOR SIMULATION EXPERTS

Context

Sub-components (Parts)	*Tier 1 Partners*	*Total Partners*
1–2 million	~10–15	~100–200
30,000–50,000	~8–12	~80–150
~40,000	~6–10	~60–120
10,000–15,000	~5–8	~50–100
3,000-30000	~3–8	~30–80

Managing Systems with many interconnected parts



Ability to

- **simulate complex cyber-physical Systems**
- **to get consistent results from multi-systems (multi-partners)**

DASSAULT AVIATION

COLLABORATIVE ENGINEERING WITH PARTNERS : CURRENT PROCESS

“Requirements”
HLTR, IRS …

Partners (LTS …)

1

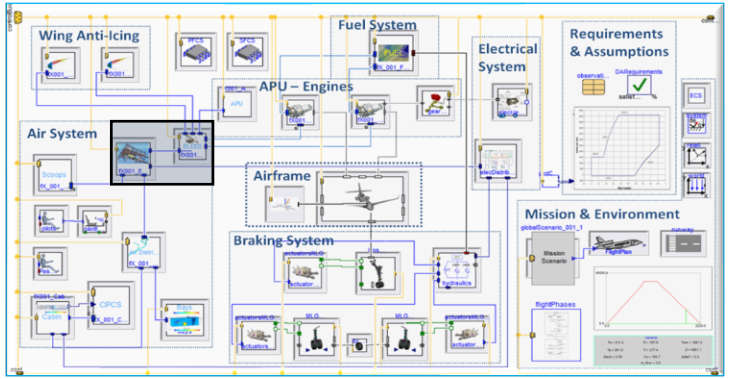
Reqs

Dassault-Aviation

Proposals

Models

2



“Specifications” SDTS …
+ **behavioral models** often difficult to integrate

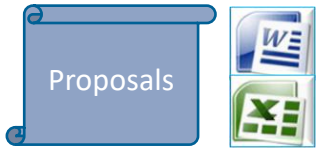
Many design loops between Aircraft Manufacturer and Partners

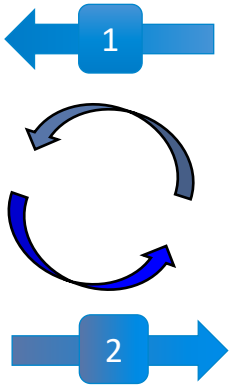
DASSAULT AVIATION

COLLABORATIVE ENGINEERING WITH PARTNERS : CURRENT PROCESS

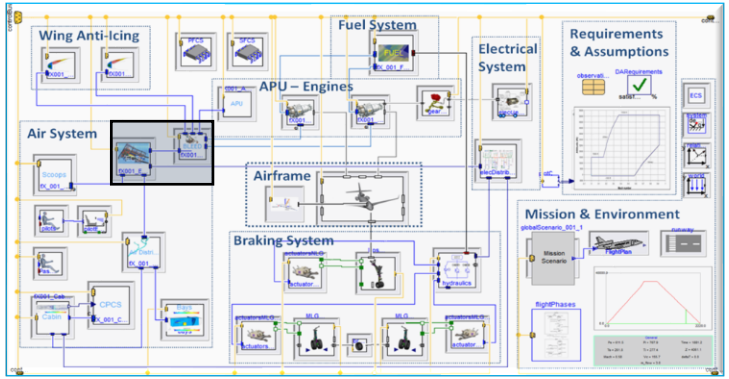
“Requirements”
HLTR, IRS …

Partners (LTS …)



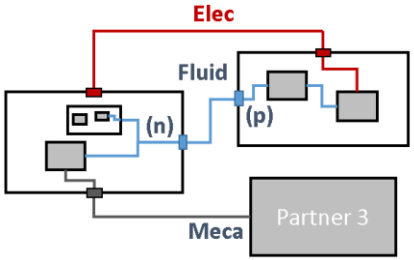


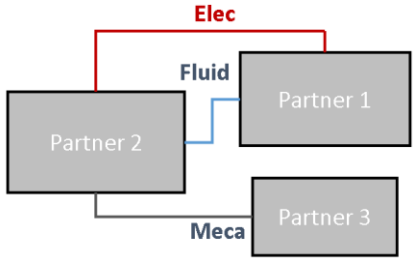
Dassault-Aviation



“Specifications” SDTS …
+ **behavioral models** often difficult to integrate

Asynchronous development between partners
sometimes not consistent interfaces => use of macro-Ports …





Recently : **share of Architecture definition, populated by Partners**
(based on SysML standard ...)
but
doesn’t solve Simulation issues

DASSAULT AVIATION

VIRTUAL TWIN ? FOR COMPLEX SYSTEMS (SYSTEM MODELS ASKED TO PARTNERS)

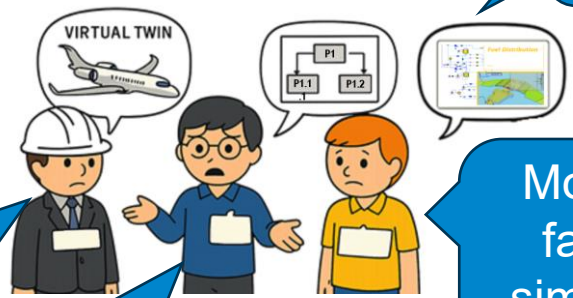
Interconnection of models is ok, but

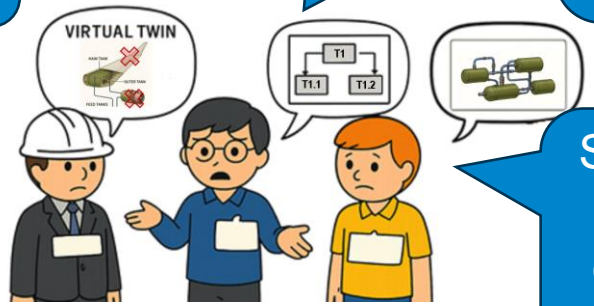
results far from reality

Much too slow

They asked a model of the system, we provided it

We don't know how they used our models





No more money

Models fail to simulate together

Sure that we could have done easily better ones

Don't understand what is within their black box models

No means to debug

Surrounding was not well known, we made assumptions

Nobody tell us about such duty-cycle

DASSAULT AVIATION

ROOTS : BUILD ABILITY TO ANALYZE AIRCRAFT VEHICLE SYSTEMS

NOT CLASSIFIED

2006 DS acquires Dynasim (Dymola)

2008 Start of Dymola integration in 3DExp)

10/2017 DS acquires No Magic

Covid

Today

Operational use : Neuron, Falcon F8X, F6X, F10X … Rafale …

2008 2009 2010 2011 2012 2013 2014 2015 2016 … 2019 2020 2021 2022 2023 2024 2025

3.0 3.1 3.2 Δ AFIS Δ DS Modelica 3.3 (+ synchronous) Δ DS Δ NAFEMS Δ AFNET Δ DS Enovia Δ AFNET Δ NAFEMS Δ Entretiens Toulouse Δ AFNET Δ NAFEMS Δ INCOSE UCODS Δ AFIS Δ DS MBSE Δ

Context

Modelica Language

Modelica Libraries

eurosyslib modelisar (libraries, basis for multi-physics .. FMI)

Modelica conference 2011 (www.modelica.org): "Modeling of System Properties in a Modelica Framework"

Modelica conference 2012 (Munich, 7-8 sept 2012): "Collaborative complex system design applied to an aircraft system"

CSDL (process and tools, surrogate models … decision support views)

EDS CLEANSKY (models for preliminary designs, electricity, thermal of cabin …)

MMT, MICADO …

Digital Twin … / Diagnostics …

www.modelica.org (Modelica Association)

www.fmi-standard.org (project of Modelica Association)

fmi Functional Mock-Up Interface

Modelica 2015 (Versailles, 21-23 Sept. 2015) « Towards Enhanced Process and Tools for Aircraft Systems Assessments during very Early Design Phases"

FP7 TOICA (collaborative system architecture design and selection)

DGAC EXCELAB

Extended Collab. Process …

ITEA2 MODRIO (diagnosis, hybrid system, dysfunctional, multi-core computations, formal requirements …)

Modelica 2015 «Formal Requirements Modeling for Simulation-Based Verification"

Internal Works / Modelica-FMI and Dymola-Catia V6-Isight-3DExperience …

Cleansky2 MISSION
Collaborative Process and tools / MIL-HIL …

ITEA **Eurosyslib** : "European Leadership in System Modeling and Simulation through advanced Modelica Libraries"
ITEA2 **MODRIO** : "Model Driven Physical Systems Operation"

Systematic **CSDL** : "Complex System Design Lab "
FP7 **TOICA** : "Thermal Overall Integrated Concept of Aircraft"
CS2 **MISSION** : "Eco-Design for Systems" / "Modeling and Simulation Tools for Systems Integration on Aircraft"
DGAC **ExceLab** : "EXtended Collaborative Engineering LAB"

Enablers to analyze complex CPS systems:

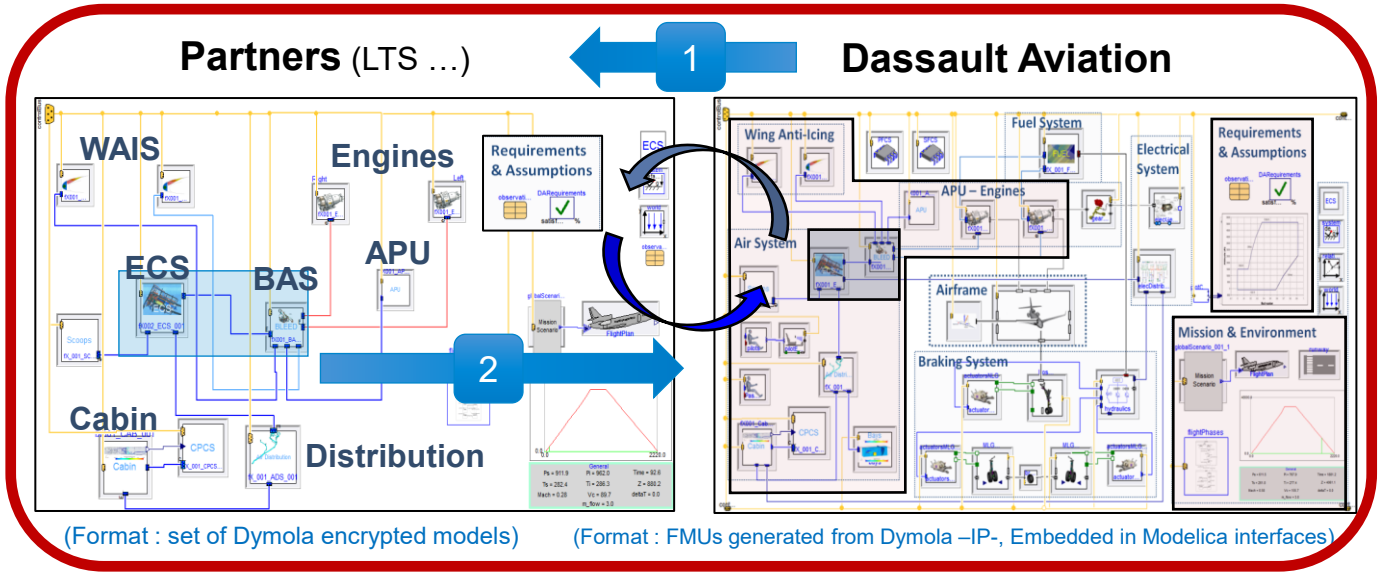
- Standards (Modelica-FMI-SysML…)
- Tools (Dymola, 3DExperience …)
- People (Designers, Architects…) …

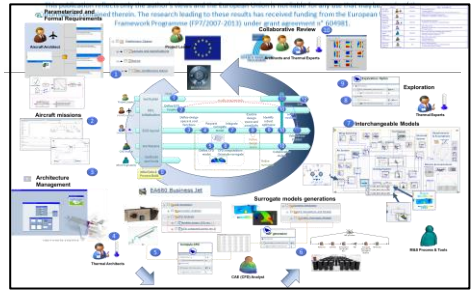
DASSAULT AVIATION

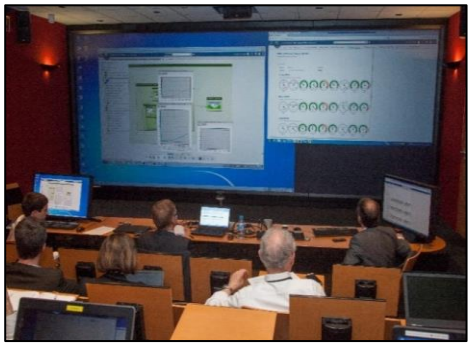
COLLABORATIVE ENGINEERING WITH PARTNERS : NEW PROCESS IN TOICA/MODRIO …

Context

- 1: **Provides Models: Interfaces, Boundaries, Mission, Requirements within Studies**







MSP6 at DA Virtual Reality Center

- 2: **Provides sub-systems models** (with the right level of details) **compatible with interfaces**, tested **within predefined environments and conditions**, and execution assumptions, **using standards** (Modelica, FMI, SysML ...)

New bi-directional agile and flexible Process for management of Collaborative Design … by defining Study needs more formally

DASSAULT AVIATION

AGENDA

Agenda

- Context
- **Enablers**
- Status
- Conclusions and Outlooks

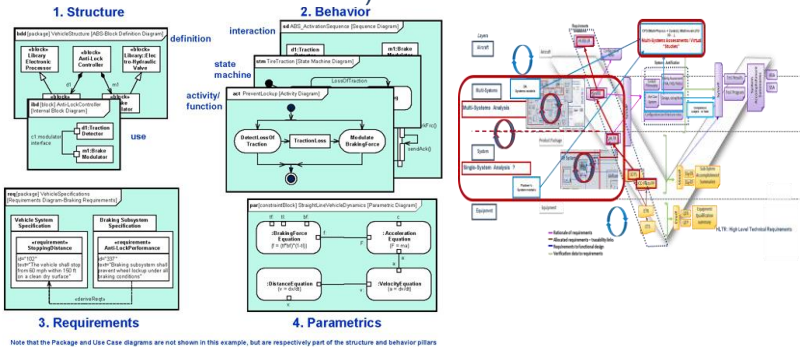
DASSAULT AVIATION

STILL A BIG GAP BETWEEN SYSTEM AND SIMULATION WORLDS, AND ASSOCIATED TOOLS

Enables

Traditional MBSE System «world»

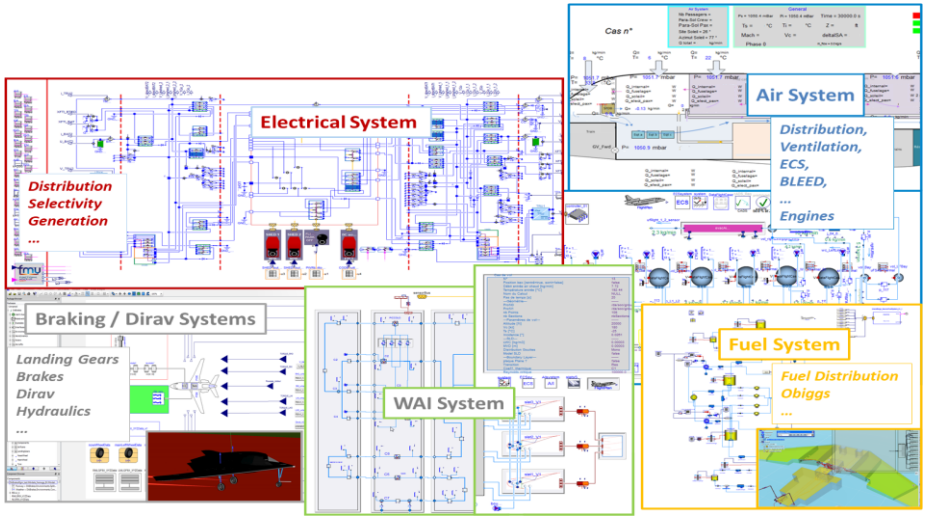
(UAF, **SysML**, UML, BPMN … RFLP, MBSE … ontology)



- **Enhanced capabilities of System modeling and queries**
- **Some simulations capabilities mainly powered by UML behaviors (state machines, activity diagrams …). Parametric diagrams not suitable for complex simulations**

Assessment-Simulation «world»

(Agents … PDE, ODE, **hybrid DAE** … Petri nets … FE, FV … MIL, SIL, HIL …)



- **Enhanced capabilities for System modeling and some capability to query results**
- **Powerful simulation capabilities of complex cyber-physic systems**

DASSAULT AVIATION

PROPOSAL : BRIDGING THE GAP BETWEEN SYSTEM DESCRIPTION AND ANALYSIS
(FROM FP7 TOICA -2013-2016 …)

Enablers

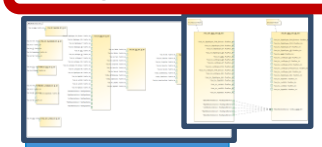
System Modeling World

System Simulation/Analysis World

Manual activity

Semi automatic activity

Automatic activity



Definition of Logical Architecture (IBD, BDD)

Operational views, Requirements

Strong link

Definition of Simulation Architecture: Set of «Studies» : {Systems, Missions, Requirements}

Generation and updates

C

Definition of a «Simulation Framework» = Set of simulation "Studies"

Populate

C

Populate with models (with IP management)

Share

"Simulation Framework" ready to be shared

Can be used by

Actors

Architects / DA Designers

Designers (DA, with Suppliers)

DA Designers / Process & Tools

DA Designers / Simulation Specialist (/ Process & Tools)

DA Designers / Process & Tools

Tools

UML-SysML / Polarsys-Papyrus-Modelio => **Cameo/Magic System**

Modelica - **FMI** (Matlab Simulink …) / **Dymola**

Projects

FP7 TOICA (2013-2016)

CS2 MISSION (2017-2020) / **DGAC ExceLab** (2020…)

UML : Unified Modeling Language
SysML : System Modeling Language

IBD : Internal Block Diagram
BDD : Block Diagram Definition
Modelica : Modelica Language
FMI : Functional Mock-Up Interface

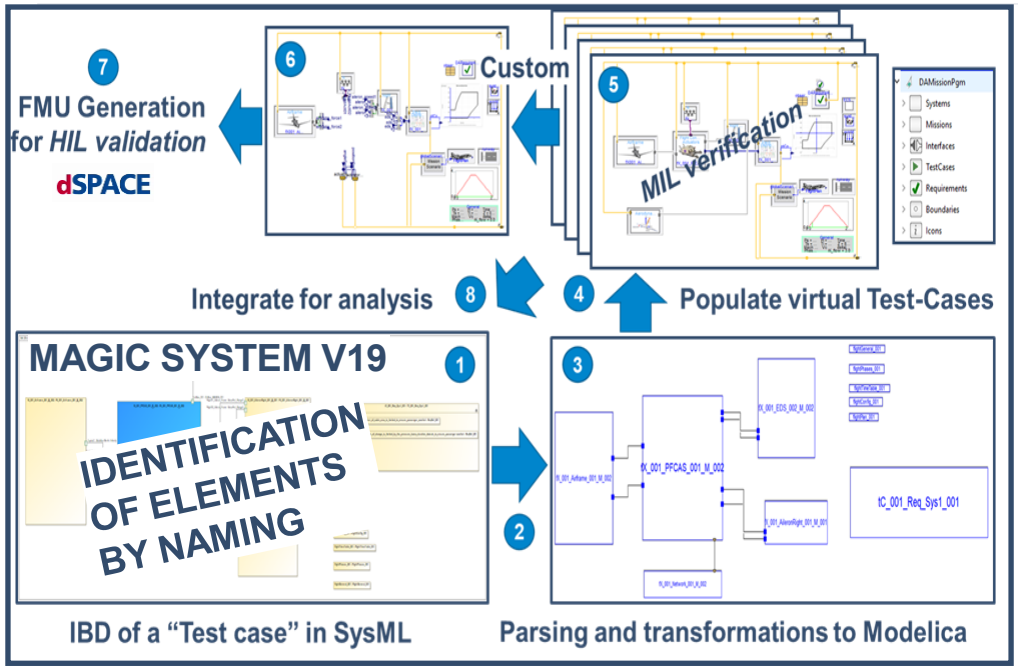
DASSAULT AVIATION

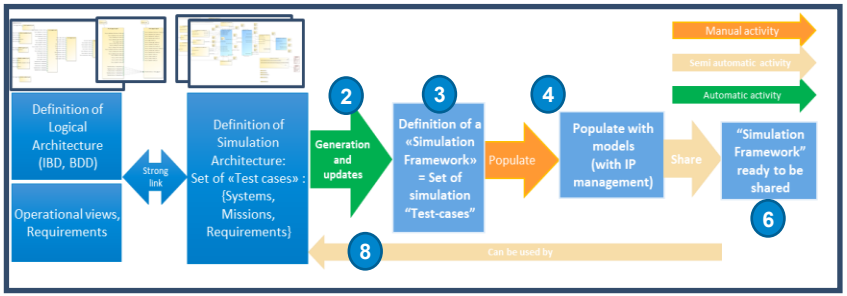
PROPOSAL : BRIDGING THE GAP BETWEEN SYSTEM DESCRIPTION AND ANALYSIS, WITH MSOSA V19 (FROM CLEANSKY 2 MISSION PROJECT -2017-2020)

Clean Sky 2 MISSION

United Technologies dSPACE DASSAULT AVIATION

Enablers





SysML / Cameo

Modelica / Dymola

DYMOLA SCRIPTS
(> 100 ADDITIONAL FUNCTIONS)
TO PARSE, TRANSFORM … EXPORTED IBD INTO MODELICA)

DASSAULT AVIATION

EVOLUTIONS : SHIFT FROM MODELICA CENTRIC PROCESS TO SYSML DRIVEN PROCESS

Enablers

	System Modeling World (based on SysML / UML)			Transform →	System Simulation & Analysis World (based on Modelica / FMI / SSP …)		
Activities	*Modeling (and several Analysis)*				*Modeling and Simulation*		
Project	Tools	Standards	Models		Tools	Standards	Models
FP7 TOICA / ITEA2 MODRIO (2013-2016)	Polarsys (=> Capella) Papyrus (CEA-List) Modelio (OBEO) …	SysML 1.2	SoI	**Gap**	Dymola (oper) + 3DExperience 203X/15x not customized (DS)	Modelica 3.3 + FMI 2.0	SoI + Mission & Configuration + Req + Behavioral models
CS2 MISSION (2017-2020)	MSOSA V19 (DS)	SysML 1.5	SoI **+ Mission (+ labelling)**	Manual native →	Dymola 2018x + Git / Bitbucket … (oper)		
ExceLab MSP1 (07/2021)	MSOSA V19 (DS)	SysML 1.5	SoI + Mission (+ labelling **+ customization from stereotypes (DSL)**	Manual native →	Dymola 2018x + Git **+ 3DExperience 2018x** (DS) **customized** (oper F10X)	Modelica 3.4 + FMI 2.0	
…							
ExceLab MSP6 (07/2024)	MSOSA 2022x (DS), + custo NGFD	SysML 1.6	**SoI + Mission & Configuration + Req + Data + DSL**	**Assisted** Native (but ≠ from v19) ← →	Dymola + 3DExperience 2020x (DS) customized (oper F10X) 2020x **(+ 2025x ?)**	Modelica 3.4 + FMI 2.0	SoI + Mission & Configuration + Req + Data + Outputs + Behav. Models
ExceLab MSP8+ and Objectives	MSOSA 2022x **- 25x** (DS) + custo NGFD + DSL + **Plugin**	SysML 1.6 **(+ v 2.0 ?)**	SoI + Mission & Configuration + Req + Data + Outputs	Assisted **customized** ← →		Modelica 3.4x **– 4.x + FMI 3.x + SSP 1.x**	

DASSAULT AVIATION

AGENDA

Agenda

- Context
- Enablers
- **Status**
- Conclusions and Outlooks

DASSAULT AVIATION

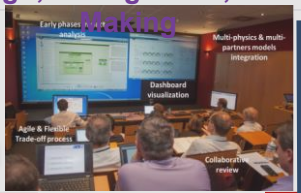
DASSAULT AVIATION – LTS USE CASE : CSDL (2020-2012) / TOICA (2013-2016) / EXCELAB (2020-2025)

Objectives

Collaborative Design, Management, Reviews – Decision

Prospects & Customers

Needs



Retex

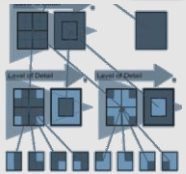
Operation & Services

Trade criteria — Aircraft System

Industrial System — Trade criteria

Collaborative Design, Management …

Aircraft System Modelling



Design partners / Equipment manufacturers

Collaborative Design, Management …

Manufacturing System Modelling

Suppliers & Logistics

dgac direction générale de l'Aviation civile — FRANCE RELANCE

Financé par l'Union européenne NextGenerationEU

DASSAULT AVIATION · AIRBUS · DAHER · LIEBHERR-AEROSPACE TOULOUSE · STELIA · ONERA · SKYDEA · CESAMES

Use cases within **EXCELAB:**

- **EX**tended
- **C**ollaborative
- **E**ngineering
- **LAB**

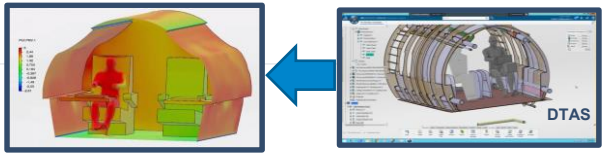
=> Demonstration plateaus every 6 months

Target:
define a **common Global method** to enable a more efficient collaboration between Airframers and Systems / Equipment Designers …

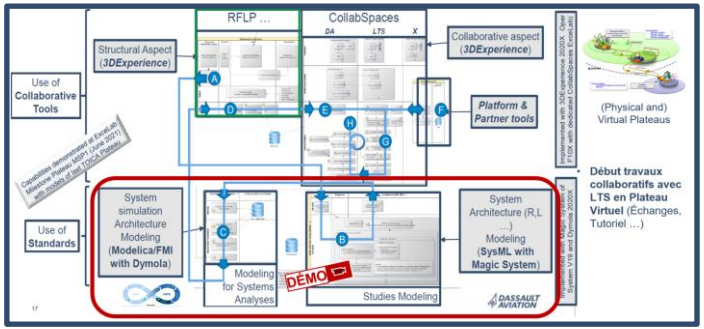
DASSAULT AVIATION

DGAC EXCELAB DASSAULT AVIATION USE-CASES

Collaborative uses cases :



1/ ***Internal collaboration within DAv*** *(capability to make complex 3D Simulation based on DMU, and to integrate it in System simulation)*



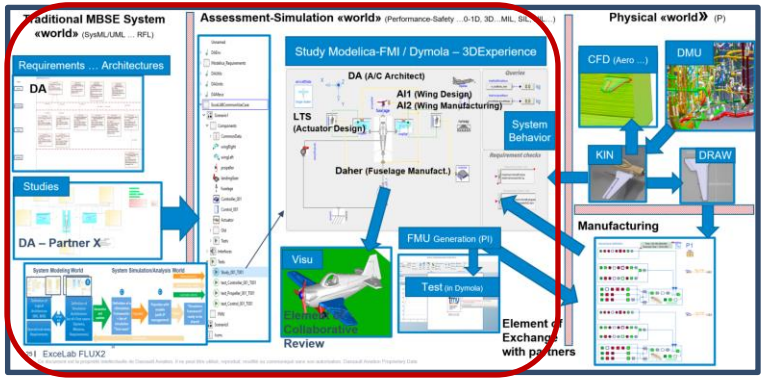
2/ ***External collaboration with Design Partners***

*Air systems assessments (**DA ⇔ LTS**)*

3/ ***External collaboration with other Design Partners***

Aerobatic Aircraft design : common use case

*(**DA ⇔ Airbus - DA ⇔ Daher**)*



DASSAULT AVIATION

EXTERNAL COLLABORATION WITH DESIGN PARTNERS : DA ⇔ LTS (SYSTEM DESIGNER)

Enablers

Use of **Collaborative Tools**

Use of **Standards**

Structural Aspect (***3DExperience***)

Collaborative aspect (***3DExperience***)

RFLP …

CollabSpaces

DA LTS X

Platform & Partner tools

Capabilities demonstrated at ExceLab Milestone Plateau MSP1 (June 2021) with models of last TOICA Plateau

System simulation Architecture Modeling (**Modelica/FMI with Dymola**)

Modeling for Systems Analyses

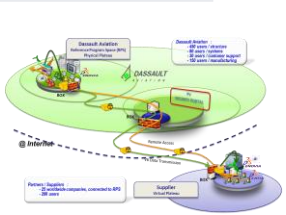
System Architecture (R,L …) Modeling (**SysML with Magic System**)

Studies Modeling

DASSAULT AVIATION

Implemented with 3DExperience 2020X Oper F10X with dedicated CollabSpaces ExceLab)

Implemented with Magic System of System V19 and Dymola 2020X

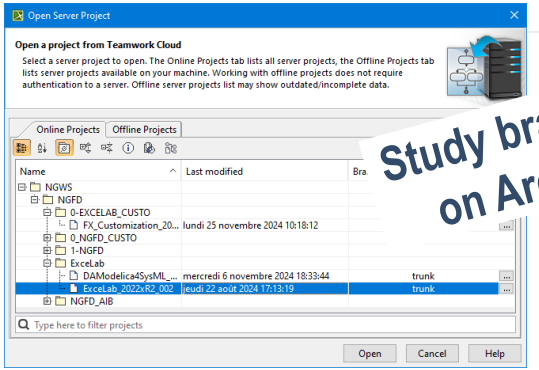


(Physical and) Virtual Plateaus

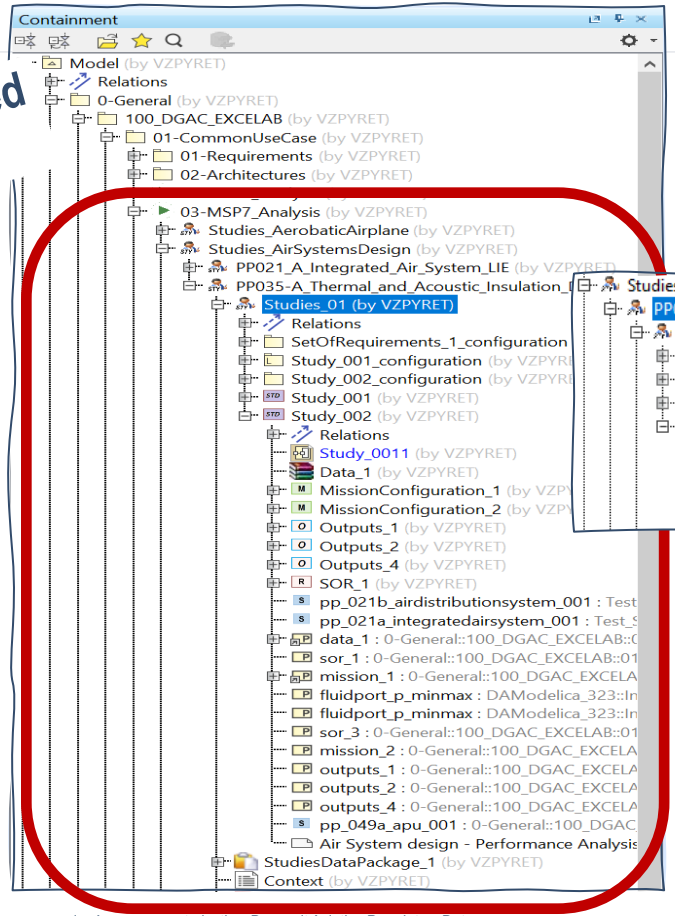
DASSAULT AVIATION

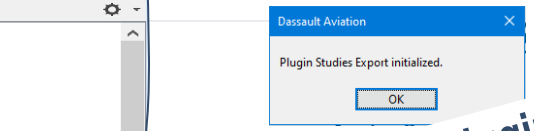
COLLABORATIVE ENGINEERING WITH PARTNERS : DEFINING COMMON BIPARTITE STUDIES (GUI)

Enablers

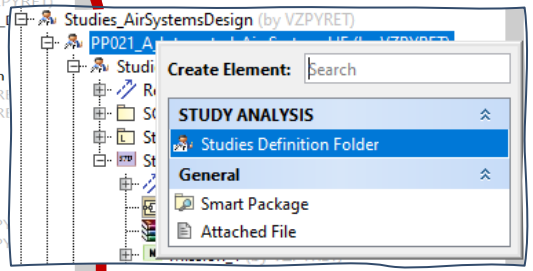


Study branch based on Architecture

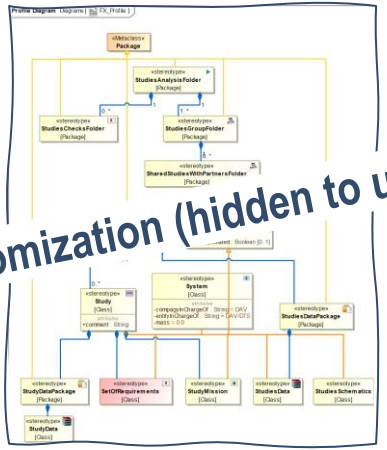




Plugin



Study Organization



Customization (hidden to users)

DASSAULT AVIATION

STUDIES ELEMENTS : FORMAL DEFINITION OF A STUDY

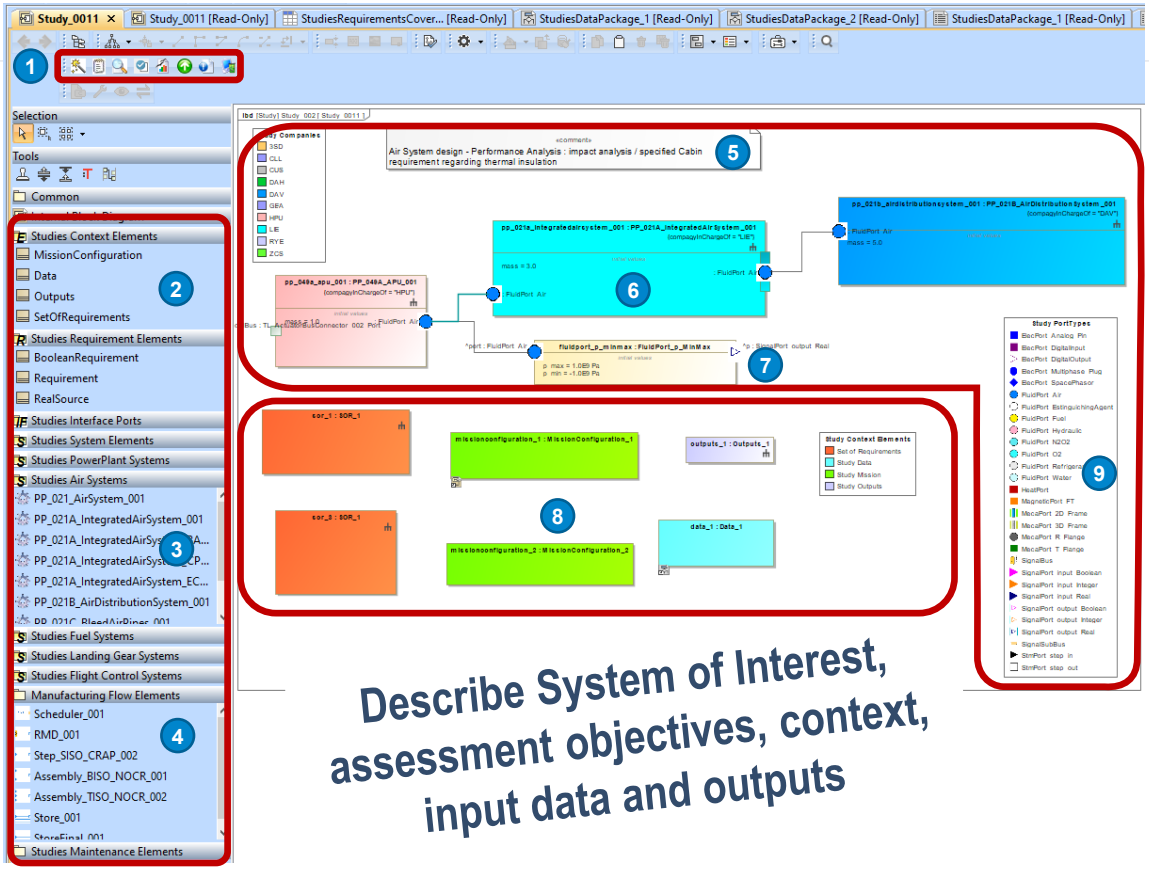
Enablers

Action Buttons
(short cuts to create instances, access GUI to add information …)

Palettes
(adding shorter way to access elements)

Easy access to Systems

Easy access to Libraries



Describe System of Interest, assessment objectives, context, input data and outputs

"System of Interest"
(from L2 Architecture and Design Partners)

Legends *(with filters)*

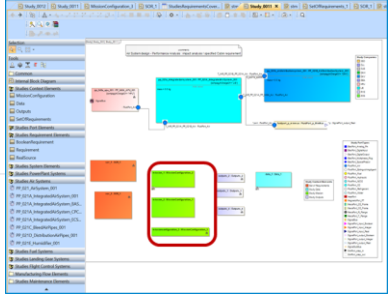
Sensors

Ports for simulation

Context elements
(Objective, Set of Requirements, Data, Mission & Configuration, Outputs)

DASSAULT AVIATION

STUDIES CONTEXT ELEMENTS : MISSION AND CONFIGURATION



Enablers

Study mission and configuration setup

Objectives | Mission | Configuration

Mission objectives

Main objectives of the Study : "Pull down assessment"

Type of objective : Check of Performance requirements

Write here the detail objectives of the Study :

Check that with worst external conditions the Environmental Conditioning System (ECS) will be able to cool down the Cabin temperature from a defined start value to a target value within a specified duration

Associated Requirements :
=> [REQ_HLTR-IAS_ECS_252]
=> [REQ_HLTR-IAS_ECS_253]

Design Partners :
=> DAV (System + Structure)
=> LIE (ECS + BAS + CPCS)
=> HPU (APU)

Study mission and configuration setup

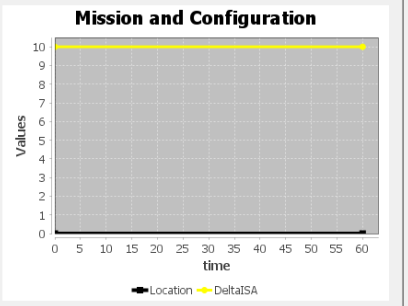
Objectives | Mission | Configuration

Mission = f(t)

Parameters

time	Locati...	time	velocity	time	deltaT...	time	angles	time	angle...
s	ft	s	knot	s	°C	s	rad	s	rad...
0,00	0,00	0,00	0,00	0,00	10,00				
60,00	0,00	60,00	0,00	60,00	10,00				

Plots



Filters

- [x] Location
- [ ] Velocity
- [x] Delta ISA
- [ ] Angles
- [ ] Angle rate
- [ ] Events

Load data from file | Save data to file | Save data to

Study mission and configuration setup

Objectives | Mission | Configuration

Context

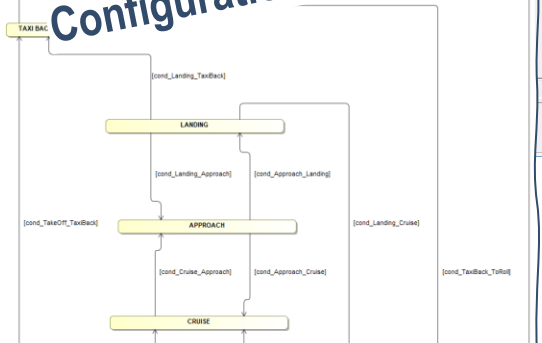
gravity field : constant | -z | comment :

Events

Tab 1

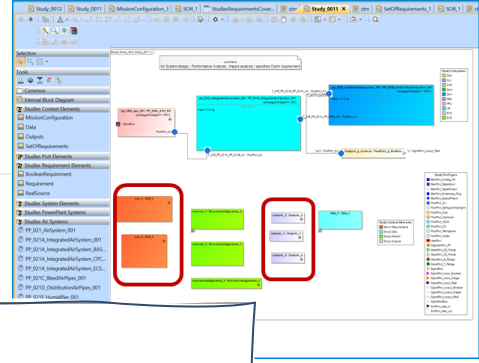
Time	Unit Time	Active	Value	Unit
0.0	min	☑	50.0	temperature
60.0	min	☑	28.0	temperature

Configuration = f(t)



STUDIES CONTEXT : OUTPUTS AND SET OF REQUIREMENTS

Enablers

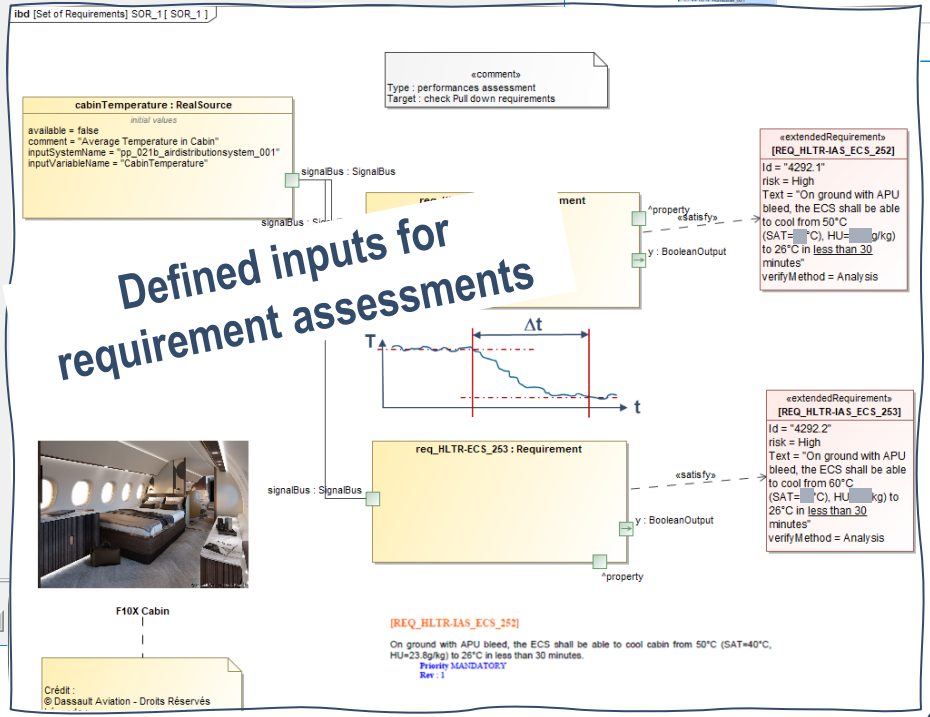


Study Analysis

System	Variable	Unit	When	Comment
pp_021a_integratedairsystem_001	ECS_MassFloxRate_001	mass flow rate [kg/s]	save at end of simulation only	ECS MassFloxRate 001
pp_021b_airdistributionsystem_001	CabinTemperature	temperature [K]	save at sample times and at end of simulation	Cabin mean temperature
pp_021a_integratedairsystem_001	ECS_InputTemperature	temperature [K]	save at end of simulation only	ECS input Temperature

Add Row | Add Row below | Delete Row | Toggle Edit Mode | Save data to model

Defined outputs with reference to System provider

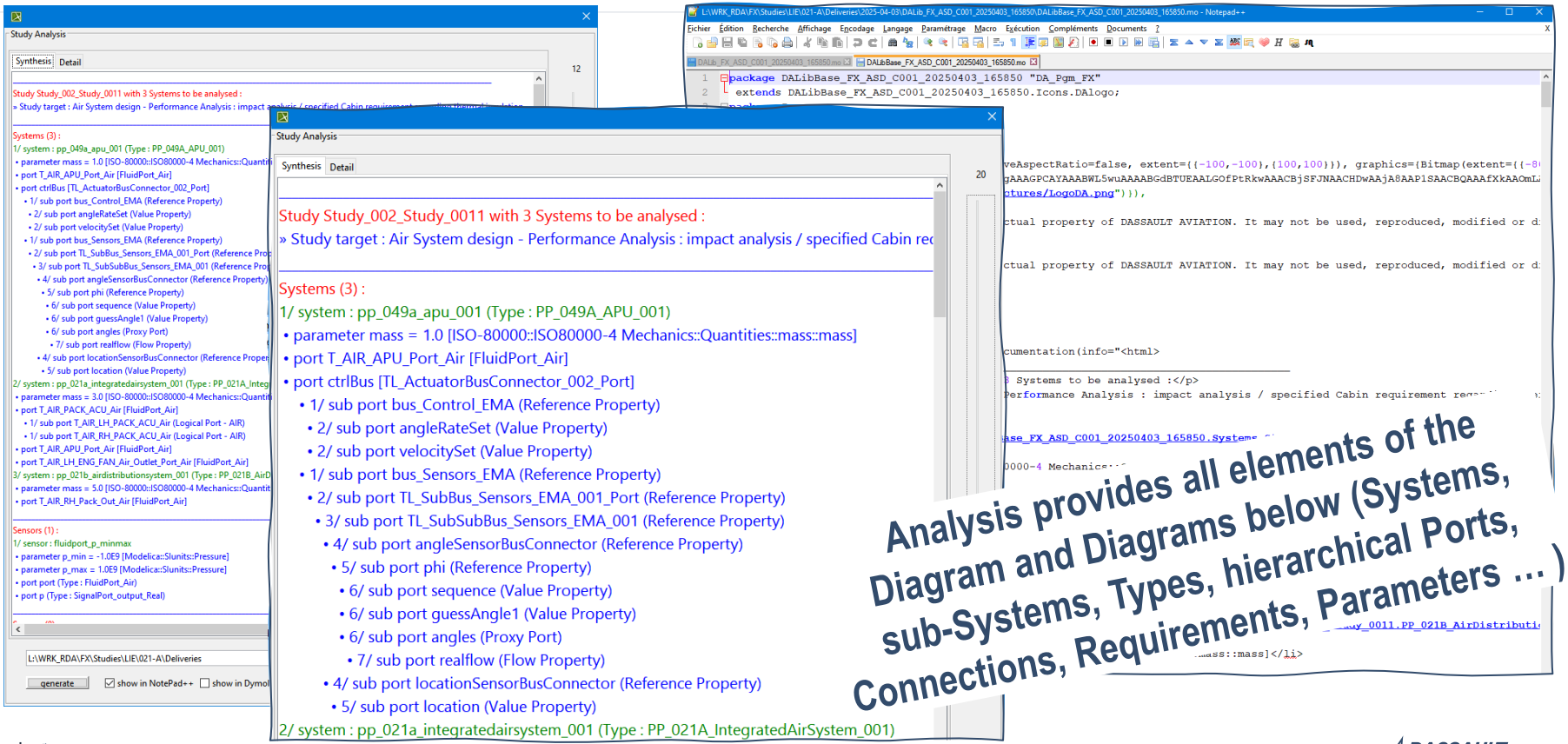


Defined inputs for requirement assessments

DASSAULT AVIATION

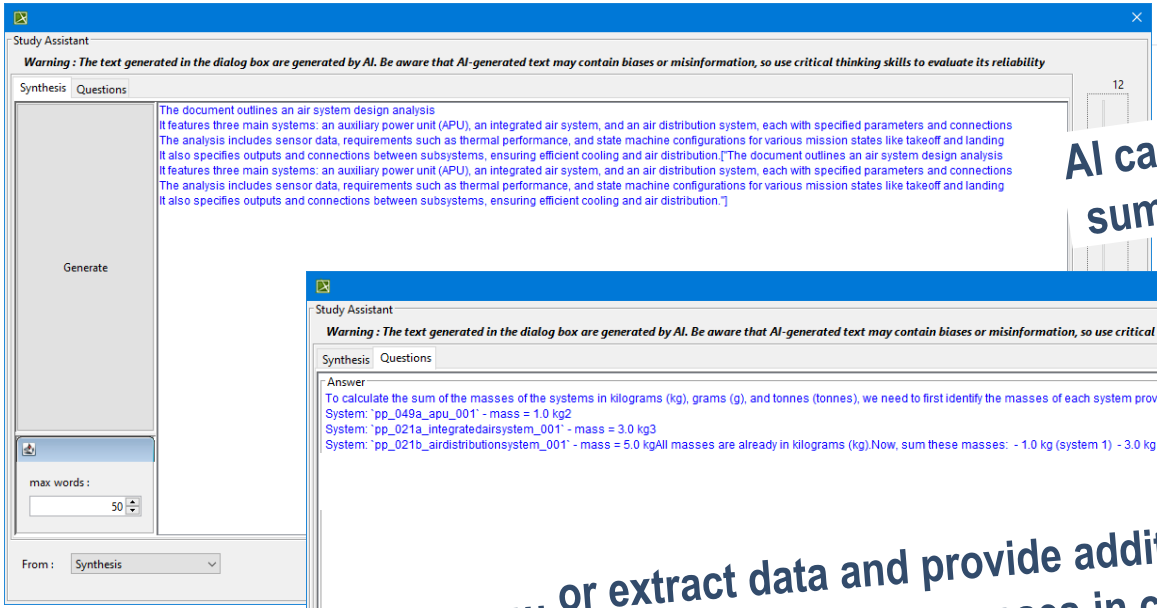
STUDY ANALYZE : ELEMENTS REQUIRED FOR CUSTOM MODELICA GENERATION

Enablers

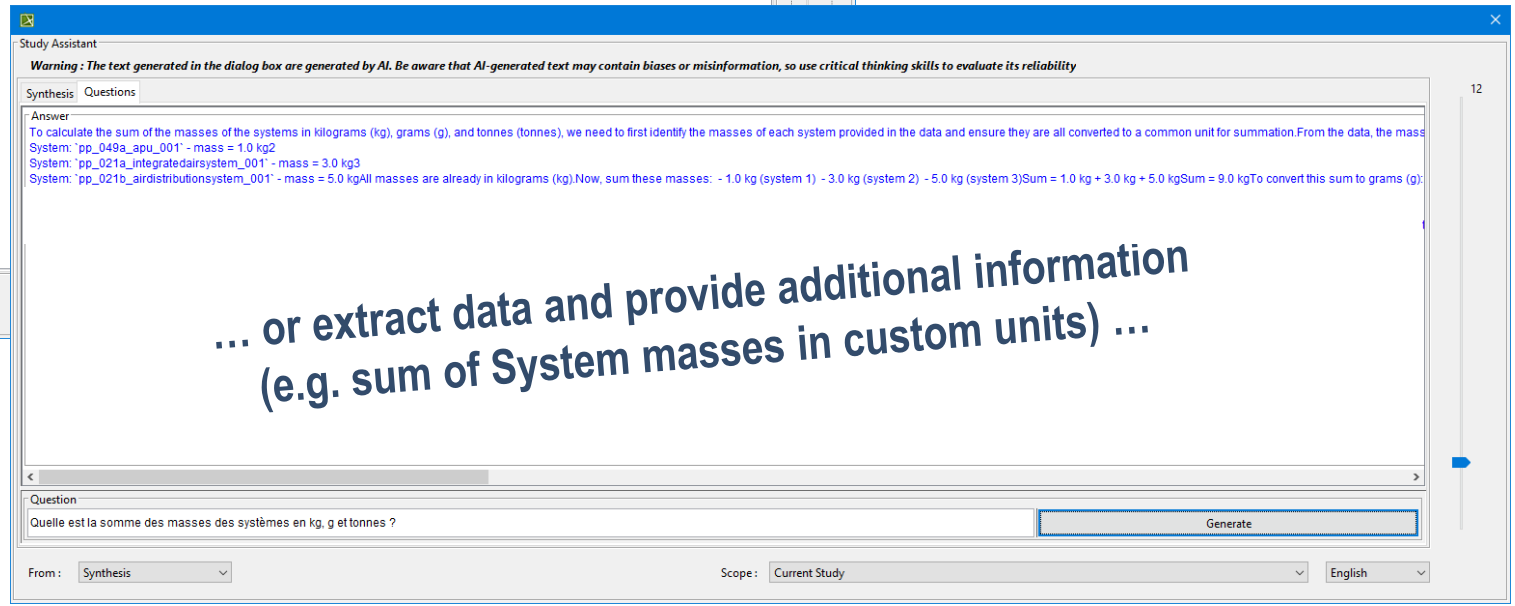


DASSAULT AVIATION

STUDY ANALYZE : EXTRA USE OF STUDY(IES) ANALYSIS USING AI LLM



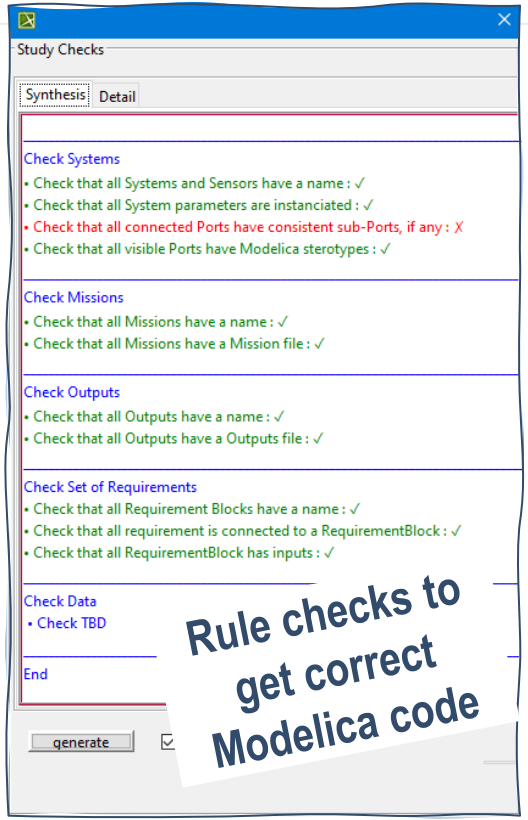
AI can make various tasks like sum-up complex information

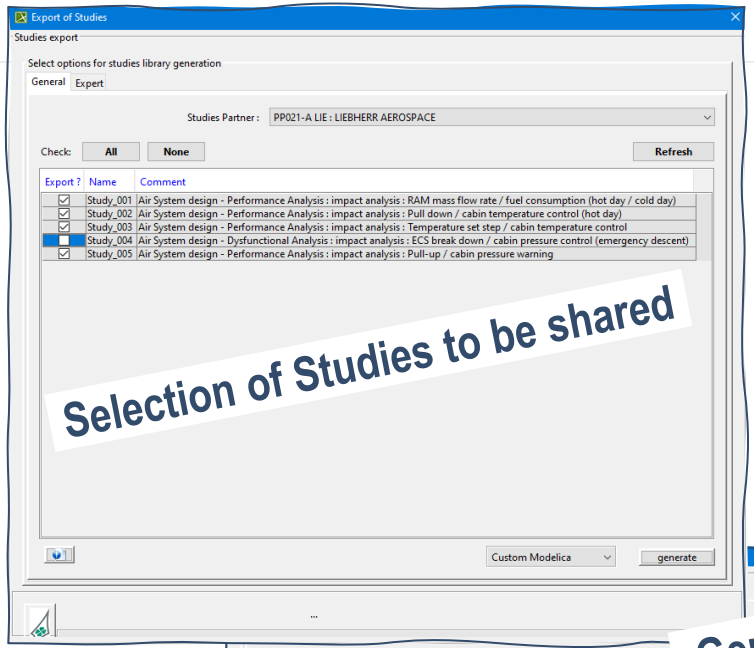


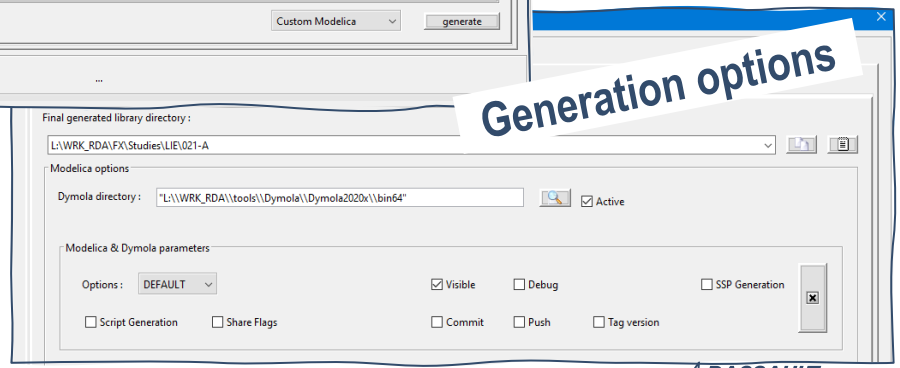
… or extract data and provide additional information (e.g. sum of System masses in custom units) …

DASSAULT AVIATION

STUDIES GENERATION : CHECKS AND SET OF STUDIES GENERATION



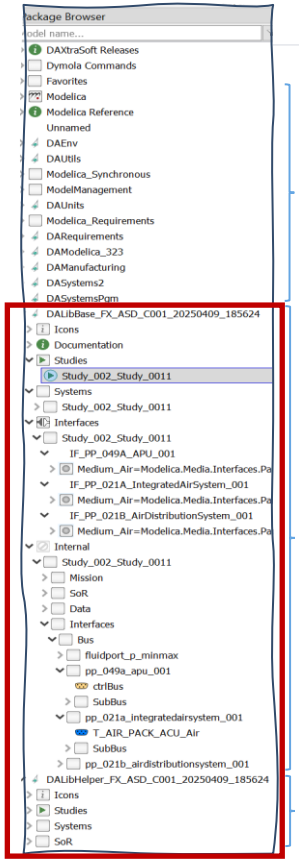




DASSAULT AVIATION

STUDIES GENERATION : GENERATED LIBRARIES

Status



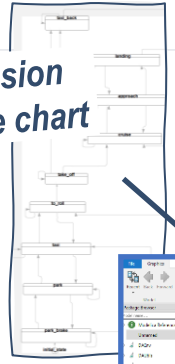
Used libraries

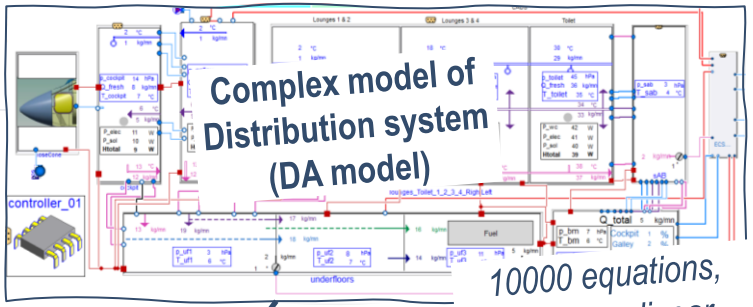
LibBase

- Study(ies)
- Systems / Study
- System Interfaces / Study
- Mission(s)
- Set(s) of Requirements
- Data
- Interface bus

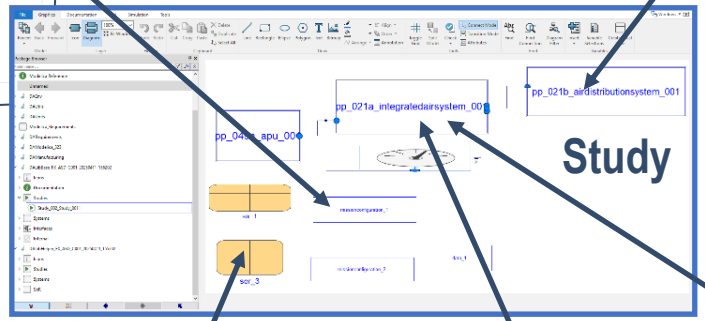
LibHelper

Mission State chart

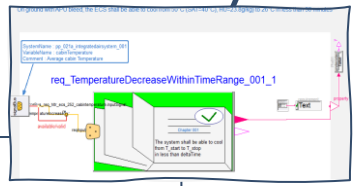


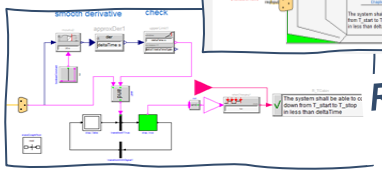


10000 equations, 3000 non linear

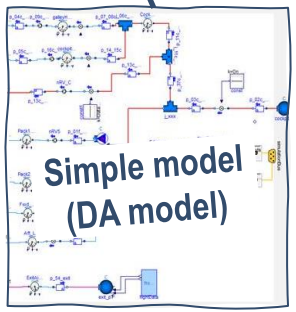


Study



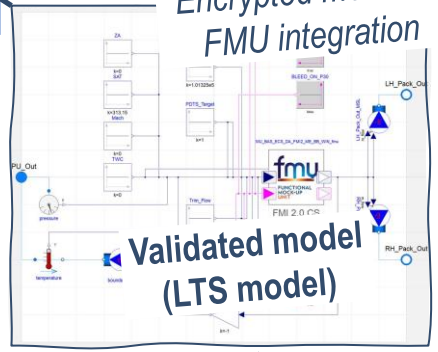


Requirement observer



Simple model (DA model)

Encrypted model or FMU integration



Validated model (LTS model)

DASSAULT AVIATION

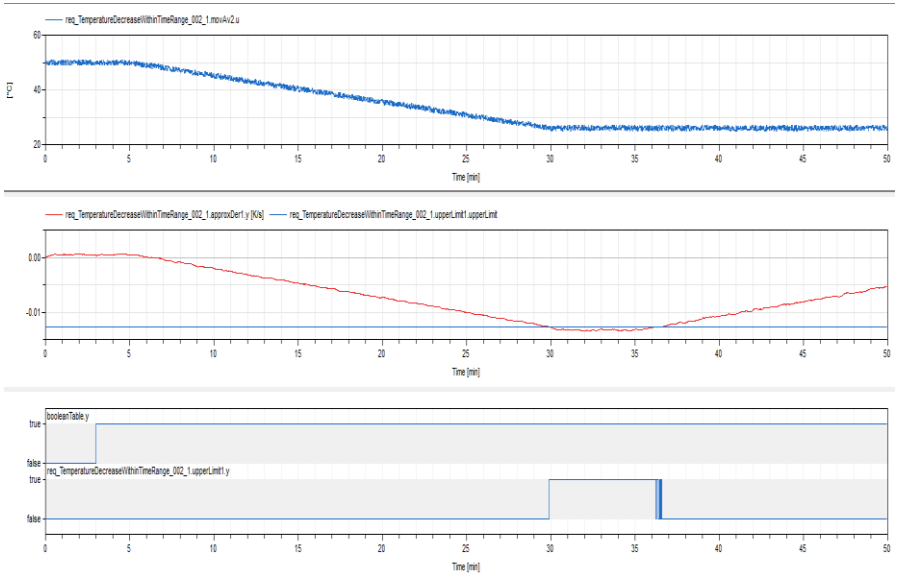
STUDIES ANALYSIS : GETTING BACK RESULTS

Status

Criteria

Element Type: Requirement ... Scope (optional): 01-Requirements ... Filter:

#	Name	Requirement text	Covered by	PP Studies Description	Requirement Results
1	4292.1 [REQ_HLTR-IAS_ECS_252]	On ground with APU bleed, the ECS shall be able to cool from 50°C (SA	Study_002 Study_001	PP035-A_Thermal_and_Acoustic_Insulation_DTAS	REQ_HLTR-IAS_ECS_252
2	4292.2 [REQ_HLTR-IAS_ECS_253]	On ground with APU bleed, the ECS shall be able to cool from 60°C (SA	Study_002 Study_001	PP035-A_Thermal_and_Acoustic_Insulation_DTAS	REQ_HLTR-IAS_ECS_252



100.0 % of test_Req_TemperatureDecreaseWithinTimeRange_002_T001 requirements are satisfied at time = 3000 s

Requirements violated (0 of 1)

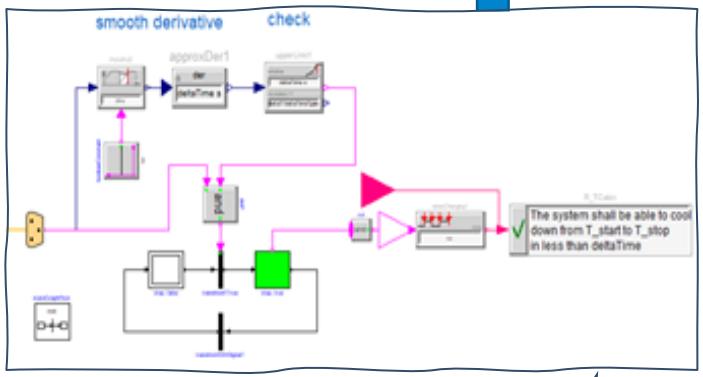
None

Requirements untested (0 of 1)

None

Requirements satisfied (1 of 1)

Observation	Requirement	Description
	req_TemperatureDecreaseWithinTimeRange_002_1.R_TCabin	The system shall be able to cool down from T_start to T_stop in less than deltaTime



DASSAULT AVIATION

APPLICATION TO THE COMMON USE CASE : STUDY "WING CHOICE"

Status

Traditional MBSE System «world» (SysML/UML … RFL)

Assessment-Simulation «world» (Performance-Safety …0-1D, 3D…MIL, SIL, HIL…)

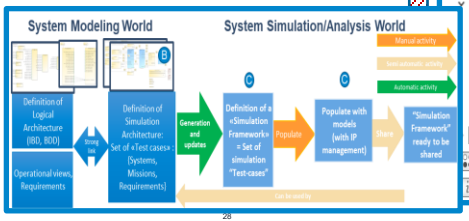
Physical «world» (P)

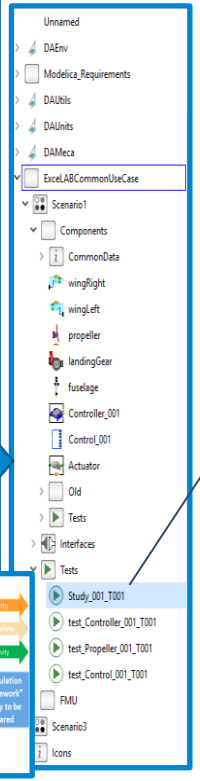
Requirements … Architectures

DA

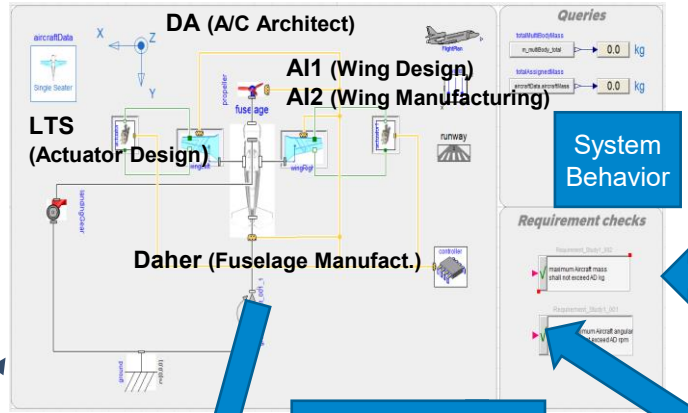
Studies

DA – Partner X





Study Modelica-FMI / Dymola – 3DExperience



System Behavior

Visu

Element of Collaborative Review

FMU Generation (PI)

Test (in Dymola)

Element of Exchange with partners

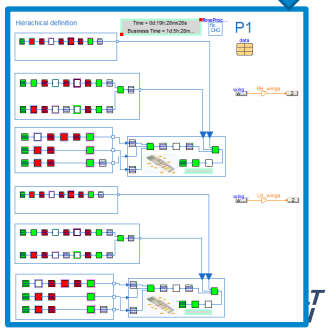
CFD (Aero …)

DMU

KIN

DRAW

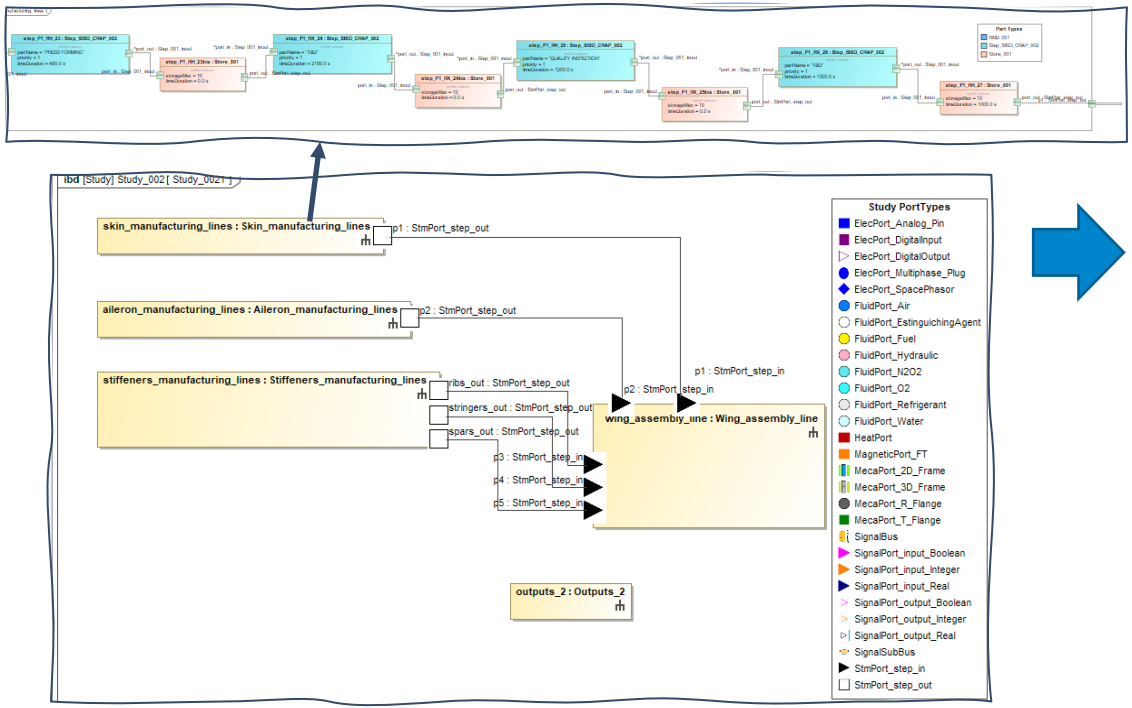
Manufacturing



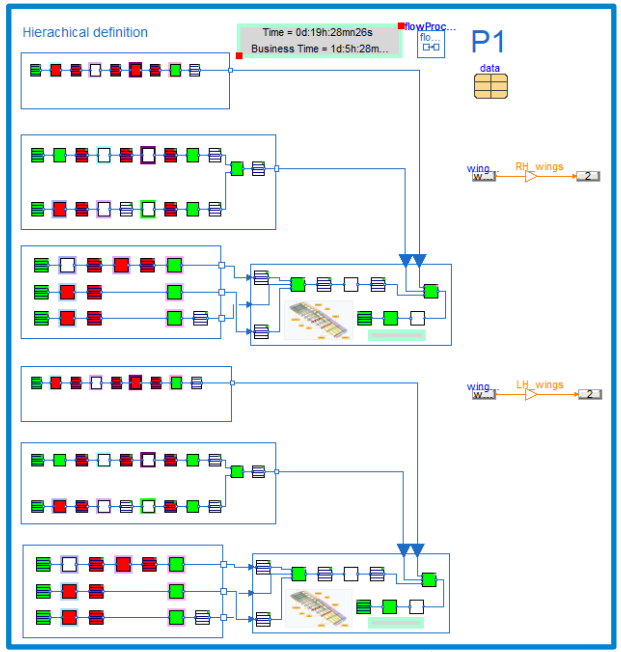
APPLICATION TO MANUFACTURING : STUDY “CAPABILITY TO MANUFACTURE WINGS”

Status

High level hierarchical definition of manufacturing workshop defined with modular parts

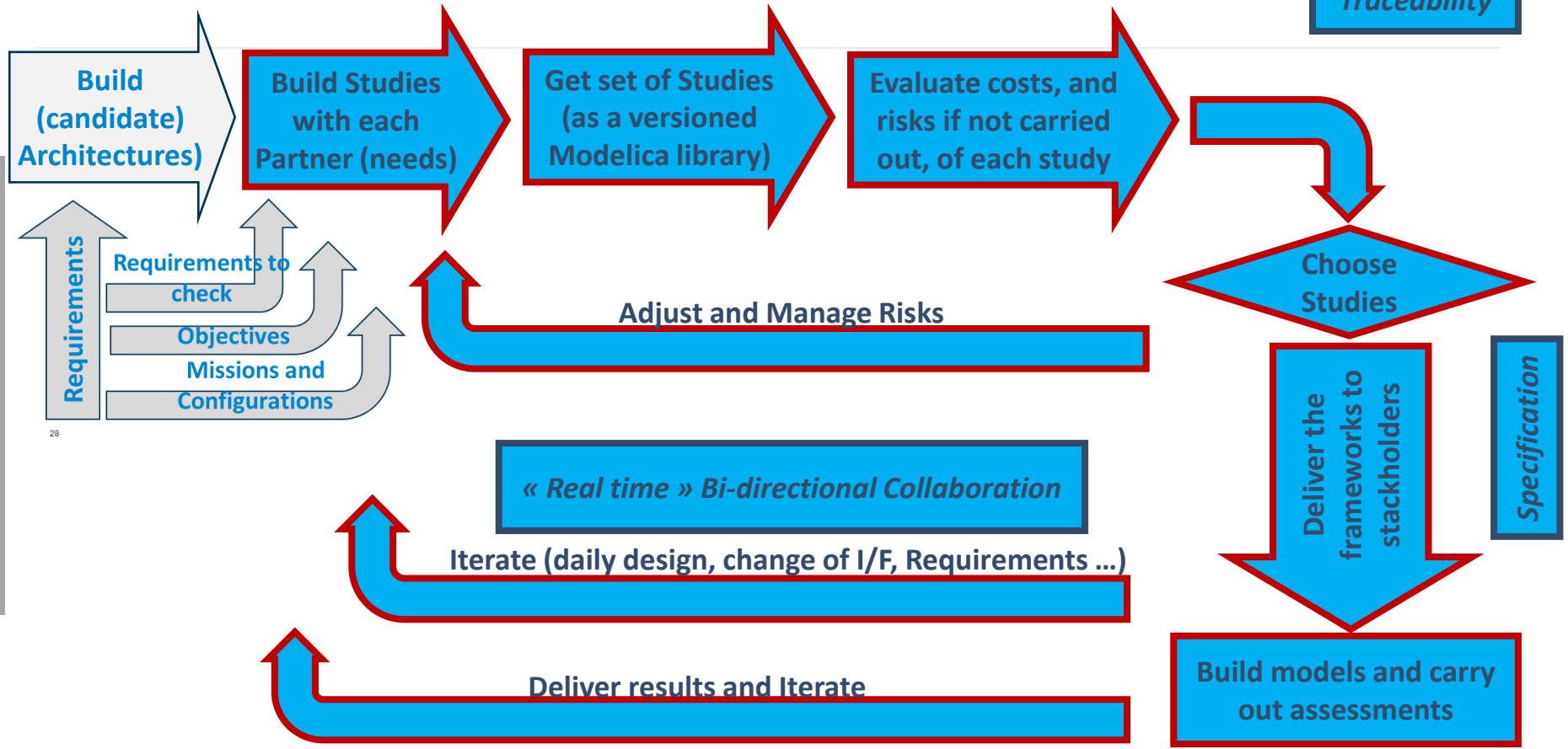


Generation in Modelica (or in other formats e.g. EKL script for Factory Flow Simulation)



DASSAULT AVIATION

STUDIES MANAGEMENT WORKFLOW



AGENDA

Agenda

- Context
- Enablers
- Status
- **Conclusions and Outlooks**

DASSAULT AVIATION

CONCLUSIONS AND OUTLOOKS

- **Integration of Multi-Systems Analysis in System Engineering**
  - **New agile and flexible collaborative process for Architectures assessments**
    - Defined and tested on prototypes connected or integrated in current operational design tools
    - **Implementation switched from a Modelica centric to a SysML driven process**, allowing
      - **a better continuity and traceability from Architectures and Requirements**
      - **better automation for checking results / objectives …**

- **Outlooks**
  - **Improvements of the prototype planned up to end of the project (end of 2025)**
    - Explore or improve other System Engineering elements (functional parts …)
  - **As much as possible test of future opportunities bring by some major evolutions of**
    - **Standards** : Modelica (4.x …), Modia, SSP (2.x …), FMI (3.x, …), SysML (v2 …) …
    - **Tools** : 3DExperience, Magic System, Dymola …

DASSAULT AVIATION