



Workshop on Aeronautical Applications of Fuel Cells and Hydrogen Technologies

# **Enhanced Model-based Development and Virtual Testing of Complex Fuel Cell Systems in Future Aircraft**

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### Located in Technology Center Hamburg-Finkenwerder

- Forum of academic and industrial cooperation
- Entry into service in 1994

### Key Data of the Institute

- Head: Prof. Dr.-Ing. Frank Thielecke
- 6 technical assistants
- 24 research assistants (01.09.2015)
- Research infrastructure, e.g. test rigs, computing, test platforms, ...



**1**

## **Motivation:**

Multifunctional Integration of Fuel Cells in Future Aircraft

**2**

## **Model-based Development:**

Multi-Stage Model Library

**3**

## **Control System Design and Validation**

Virtual Integration and Scenario-based Testing

**4**

## **Diagnosis System Development**

Software Package SPYDER

**5**

## **Virtual Integration Platform VIPER**

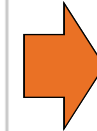
**6**

## **Contributions to a Joint Project**

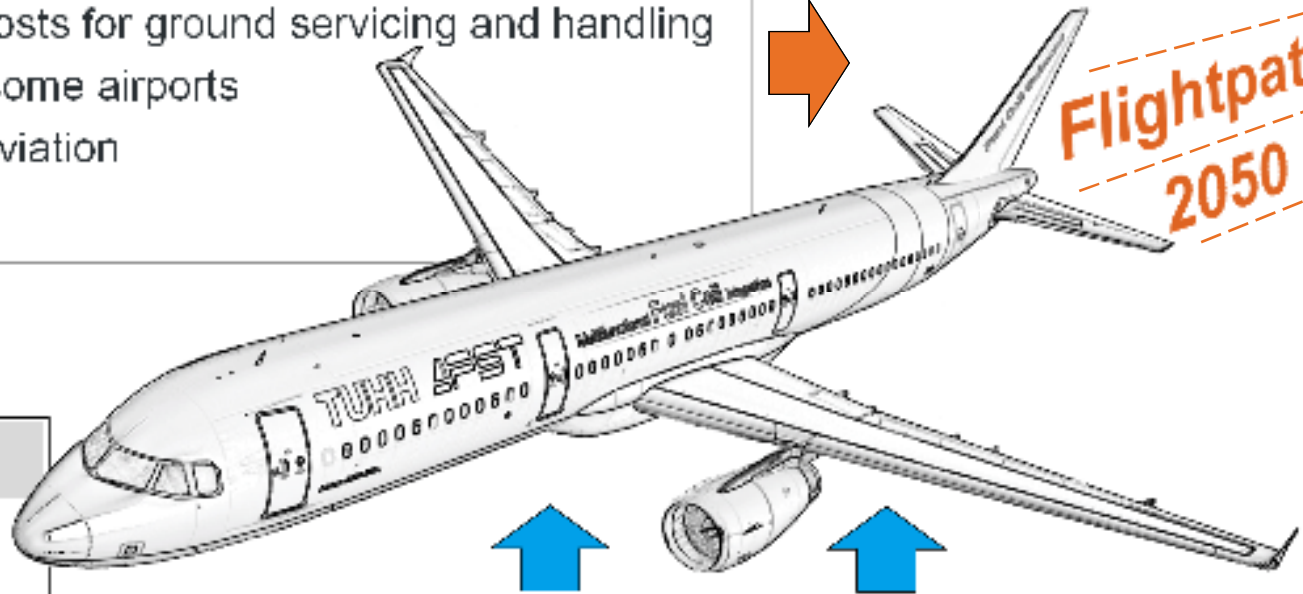
# 1. Motivation: Fuel Cells in Future Aircraft

## Environmental & Economical Aspects

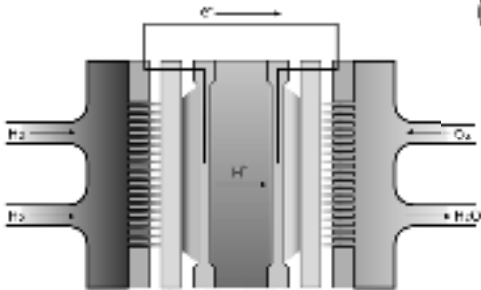
- Interdiction of the APU during ground operation at some airports → Additional costs for ground servicing and handling
- Fees for emissions at some airports
- Emissions trading for aviation
- Increasing fuel costs



Flightpath  
2050



## Fuel Cell Technology



- No polluting emissions
- High efficiency



## Multifunctional Integration

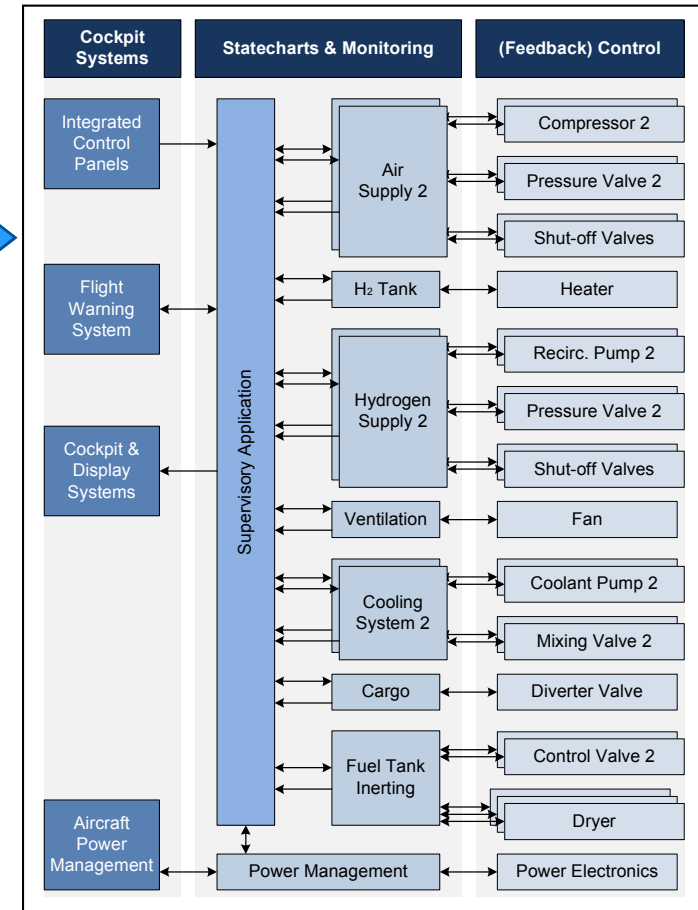
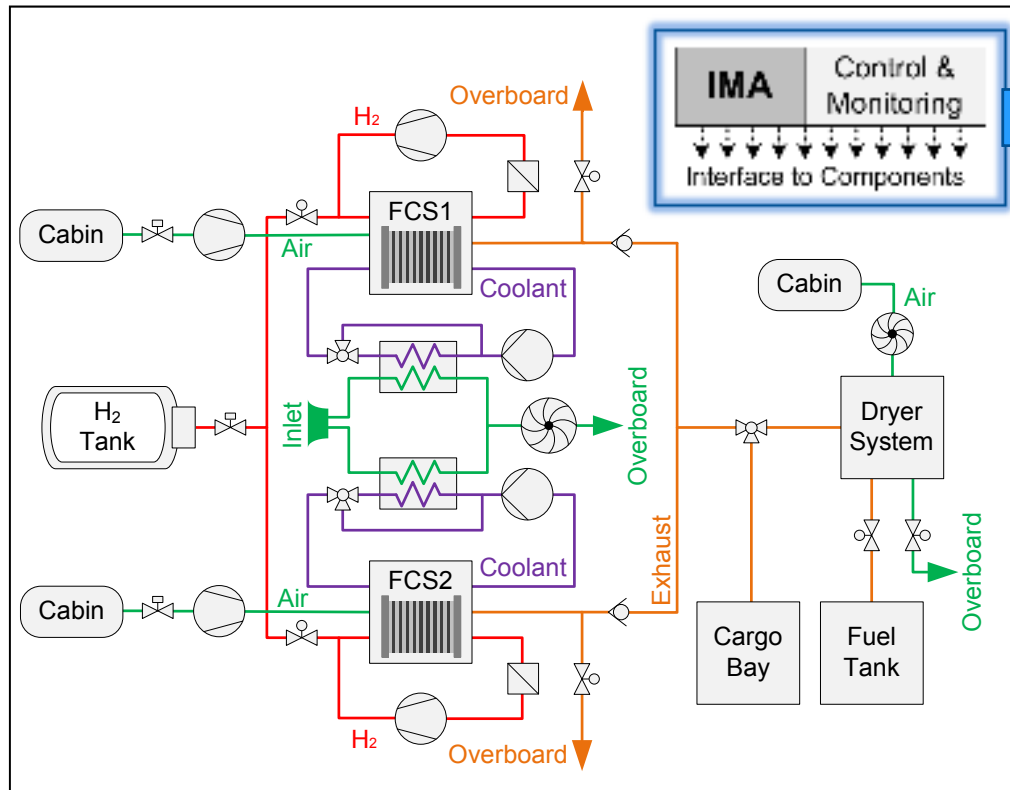
- Electrical power source for ground operation
- Emergency power supply during flight
- Fuel tank inerting
- Cargo bay fire suppression





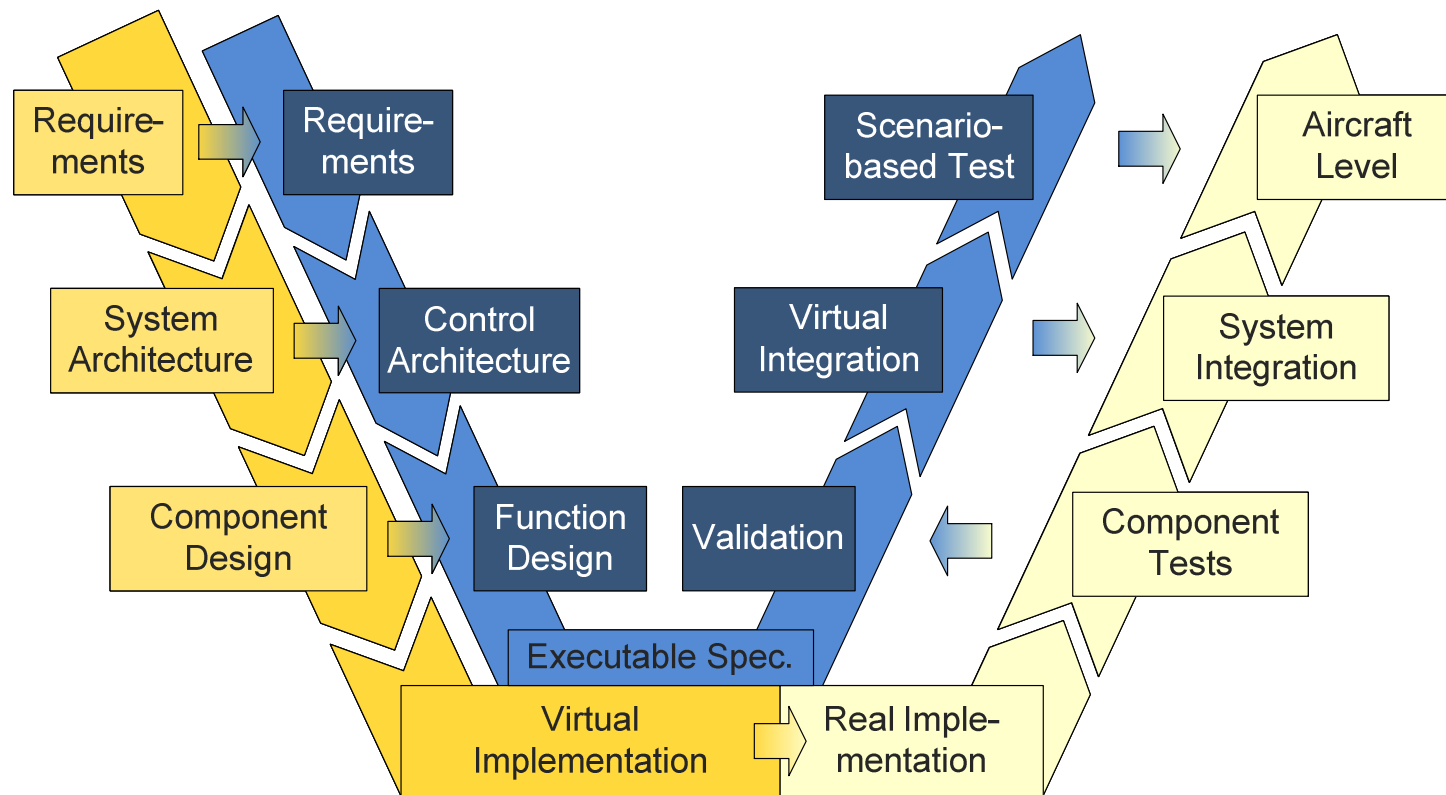
# 1. Motivation: Multifunctional Operation of Fuel Cells

- Substitution of the auxiliary power unit by two fuel cell systems
- Integration of exhaust conditioning system
- Control and monitoring functions on IMA platform
- Hierarchical structure of control and monitoring system



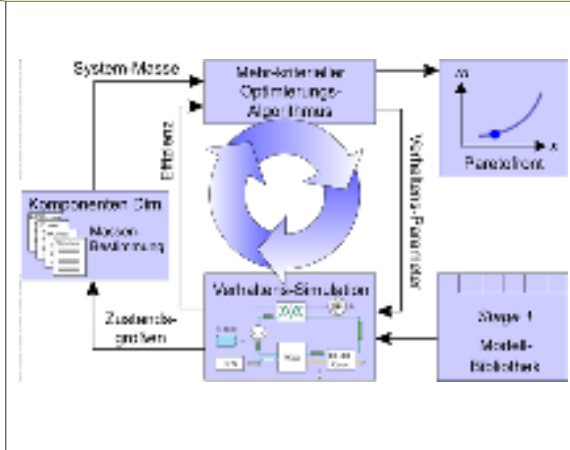
## 2. Model-based Development: Enhanced V-Model

- Development process based on common V-Model
- Model-based design of system architecture
- Model-based design of software system (Control & Monitoring) embedded in V-Model
- Enhanced by virtual integration and scenario-based test approach



## 2. Model-based Development: Multi-Stage Model Library

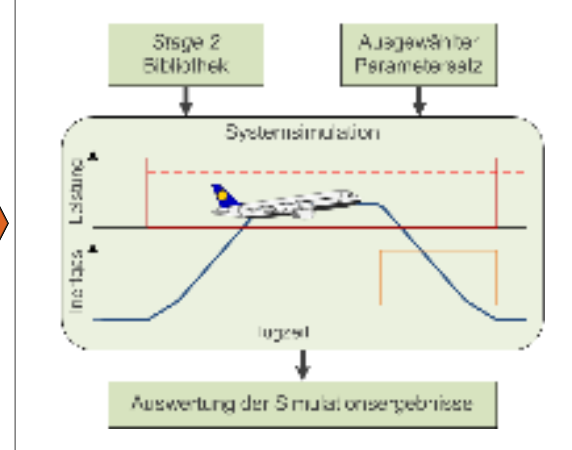
### Design & Optimization



### Stage 1

- Stationary behavior for design point
- Utilization of behavior parameters

### System Validation

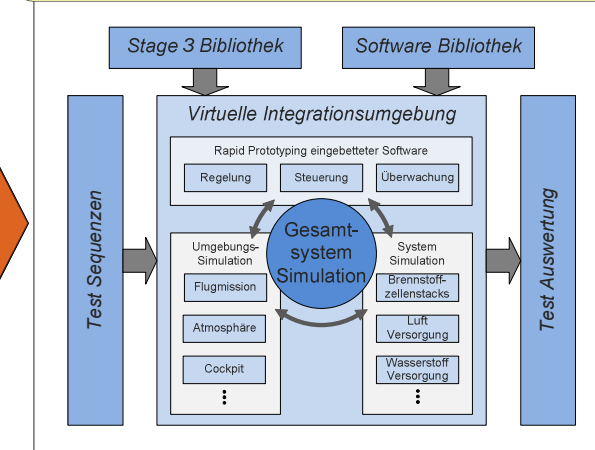


### Stage 2

#### Features of Model Stages

- Stationary behavior for any operating points
- Consideration of component geometries

### Virtual Integration



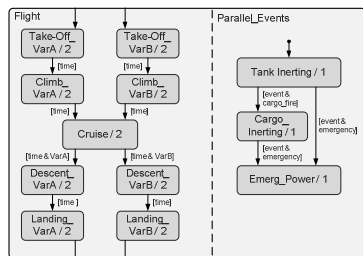
### Stage 3

- Dynamic behavior for all operating points
- Consideration of failure cases

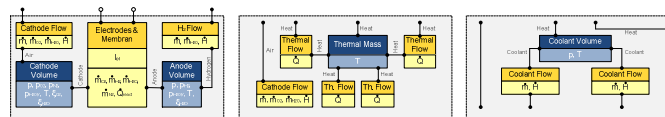
# 3. Virtual Integration and Scenario-based Testing

- Integration of Automation System in overall system simulation
- Automatic generation of test scenarios
- Analysis and evaluation of system behavior by Evaluation Agents

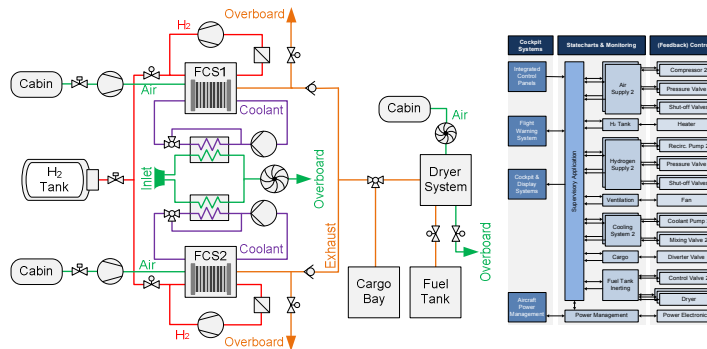
## Scenario-based Test Generation



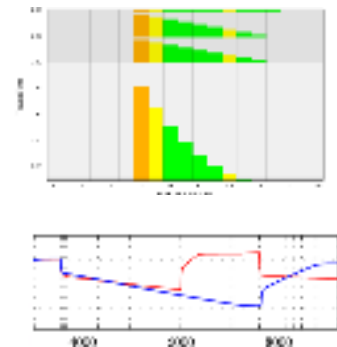
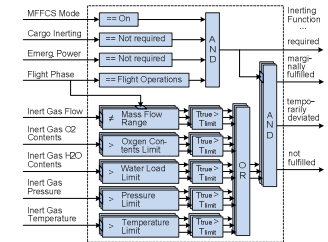
## Library & Physical Modeling Approach



## Integrated Simulation of System with Control and Monitoring Functions

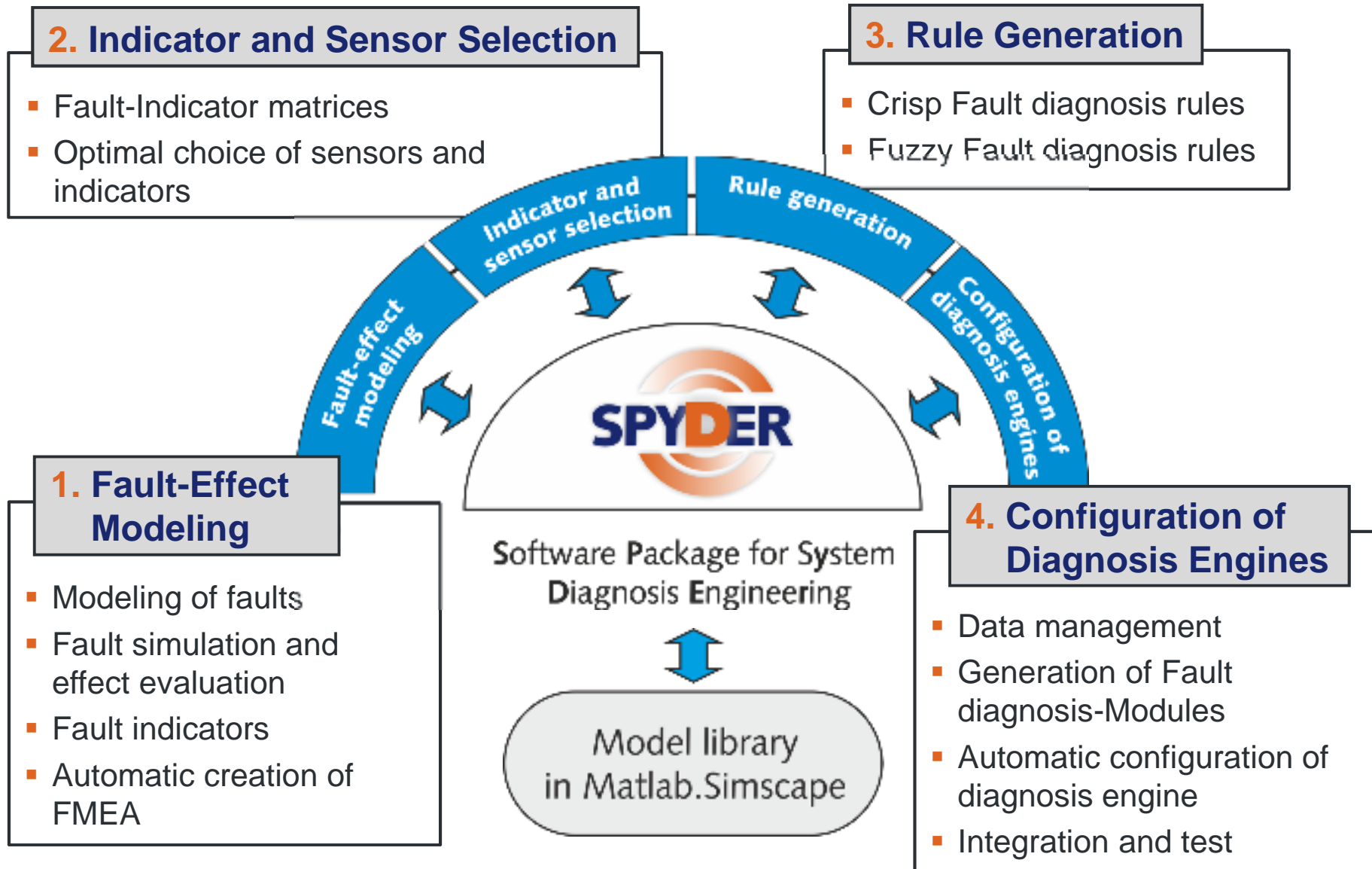


## Agent-based Test Evaluation & Results



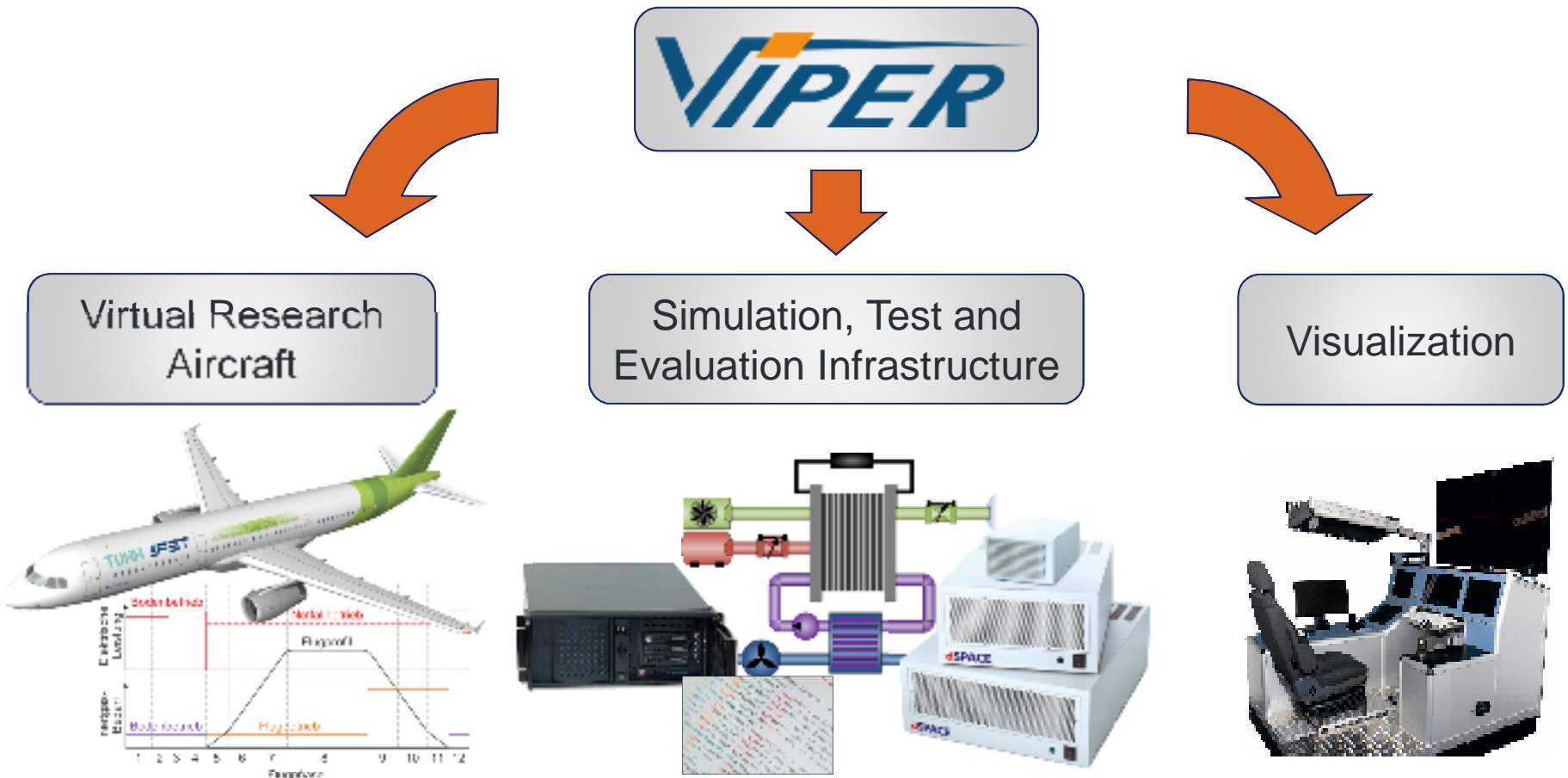


## 4. SPYDER - Software Package for SYstem Diagnosis EngineeRing



## 5. Virtual Integration Platform VIPER: Concept

- Simulation and analysis of overall aircraft architectures including embedded software
- Virtual integration of aircraft systems considering flight dynamics
- Realtime control, simulation and visualization infrastructure



## 5. Virtual Integration Platform VIPER

Virtual Research  
Aircraft (ViRAC)

Engineering Cockpit  
Simulator (ECOS)

System  
Visualization

## 6. Contributions to a Joint Project

- ▶ **MBSE: Model-based Development of Complex Fuel Cell Systems in Future Aircraft**
- ▶ **Design of Control and Monitoring Functions for Fuel Cell Systems**



**VIPER**



- ▶ **Design of Diagnosis Systems using Software Package SPYDER**
- ▶ **Perform Scenario-based Integration Studies using the Virtual Integration Platform VIPER**



***Thank you...  
... for your Attention !***



***Do you have Questions?***

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