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The Expanded Reach of Simulation Based Aircraft System Verification and its Software Capability Requirements

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The use of simulation in the development of aircraft and aircraft systems has become prevalent throughout the domain of the aircraft product development process. This paper will focus on the segment of simulation that includes real-time simulation, real-time test, and their surrounding technical areas. As the value, in terms of utility per dollar, and capability of commercial and open source tools has grown, and as the techniques associated with real-time simulation and real-time test have evolved, simulation based test, using real-time simulation systems, has grown without bound. Open source software and the standards that comprise the COTS computer hardware market have created a highly competitive technology marketplace that appears to have many years of Moores Law style increases in benefit to offer the aircraft product market. Rapid advances in aircraft technology and growth in the sophistication of this technology is requiring more sophisticated methods of developing, integrating, testing, and certifying systems be employed. Luckily, when done well, the investment in simulation based aircraft testing software, systems, and IT infrastructure has offered significant returns and has resulted in risk mitigation, reduced loss of life, less flight testing, and brings new technologies into the products much quicker than previous processes [1].

The move to a "More Electric Aircraft" [2-9] and the addition of a high-speed, Ethernet based networking backbone within the aircraft are keeping development, verification, and certification teams very busy. These technologies are opening the door to a path of safety, efficient, and comfort advancements for the foreseeable future. With a four trillion dollar plus twenty-year commercial aircraft market forecast, investments in these aircraft product advancements appear to be easily warranted. These technologies unavoidably add complexity and greater interoperability to the aircraft. This added complexity and connectivity requires that more advanced and efficient techniques be applied to the development, integration, verification, and certification of each system and all systems combined. Real-time, hardware-in-the-loop, pilot-in-the-loop simulation, and real-time open-loop testing have become the go-to approaches to help bring down to size an ever-increasingly challenging set of tasks. These methods are found in iron bird simulators, aviation integration labs, cockpit development and verification labs, and in the system verification departments at the typical aircraft subsystem supplier. This paper examines those open source software technologies and standards based electronics technologies that are leading the adoption battle in the world of simulation based test and explores the characteristics of the winner versus the losers. This is presented against a review of the software and hardware capability requirements and new technology that is making its way into the capability space.

The aircraft industry is accumulating an incredibly valuable set of intangible “simulation assets” on their respective balance sheets. Over the past two decades there have been many lessons that have been learned regarding the dos and don’ts of this asset accumulation effort. This paper reviews and explores these lessons and how they’ve guided this technology’s evolution.

Introduction

The engineering and technology space surrounding Model Based Systems Engineering (MBSE) has been growing in scope and importance for product development companies, for at least a couple decades. Product Lifecycle Management (PLM) methodologies allow product companies to shorten development cycles, reduce cost, and refine the product offering to enable each successive version to be better, cheaper, faster. Matlab/Simulink has become the Microsoft Word of technical computing and the leading format for designing and simulating product behavior.

In the decade from 2000 to 2010, a tremendous amount of technology advancement was seen using Simulink models to design a system, and use Simulink-interfaced code generators to output C code providing the behavioral capability associated with any intelligent subsystems within the designed system. This, along with other advancements in MBSE, has allows for the more and more complexity to be designed into a system while at the same time reducing product design cycles. Added complexity to provide a larger feature set, reduce energy consumption, reduce initial and maintenance costs, improved user experience, etc. have expanded the effort associated with the system verification tasks. More and more work is being placed on the systems verification team whose role is to ensure the product does exactly what it was designed to do, and nothing else.

The MBSE world is seeing an increased investment in model based systems verification teams, facilities, software, and business process to expand what is, for many product companies, a bottleneck in their PLM business operations.

The aircraft manufacturing market is a very interesting product business. Like many product companies, aircraft manufacturing involves product certification and rigorous PLM methods. The certification of an aircraft requires that each aircraft system be tested to ensure they meet all system requirements, and meet system-specific airworthiness standards. Then systems must be integrated as incomplete and complete sets to be verification tested ahead of the Flight Test. The Flight Test Program represents the final system integration testing effort. Model based verification involves testing one or more systems interfaced with simulation in order to put the system(s) through normal and failure mode conditions that are highly representative of the complete aircraft behavior.

This activity involves a wide range of artifacts including simulation models, requirements documents, design documents, traceability matrices, test framework projects, facilities, product domain experts, test cases, verification software, real-time computer systems, and prototype aircraft systems. Each of these artifacts is being refined and is evolving through the product lifecycle. This results in a challenging management tasks in order to perform model based system verification in a timely and cost-effective manner. This paper reviews the historical trend of model based systems verification for aircraft, reviews the traditional methodologies and facilities that have become industry norms, looks at the software capabilities and requirements associated with a world-class model based verification process, reviews the MBSE verification process itself, and reviews in-detail, some of the new MBSE verification facilities being used in the aircraft manufacturing market, and discusses business process trends associated with this fast-changing area of the PLM world.

Traditional Simulation Based Aircraft Test Facilities

Iron Bird test rigs have been used in the aircraft industry for more than four decades. Initially, these test rigs were used to integrate and test the aircraft's mechanical and hydraulic flight control actuation system. Later, real-time simulation was added to the test capability to enable the testing to take the system through a wider, and more representative, set of tests. Today, Iron Bird facilities are commonly built for every aircraft program executed by a major manufacturer.

The simulation based cockpit testing facility has been around as long as pilot-in-the-loop flight simulation has been in existence. Simulation based pilot training facilities are a large market business and very different than typical engineering cockpit simulators. Like Iron Bird facilities, every major aircraft manufacturer builds an engineering cockpit simulator for each of their new aircraft programs.

As aircraft avionics facilities have become more complex, more interdependent, and providing more safety-critical capability, the use of the Avionics Integration Facility has also become standard fare for serious aircraft manufacturers.

Each of these three traditional types of MBSE verification testing facilities is described in detail below.

Iron Bird facility

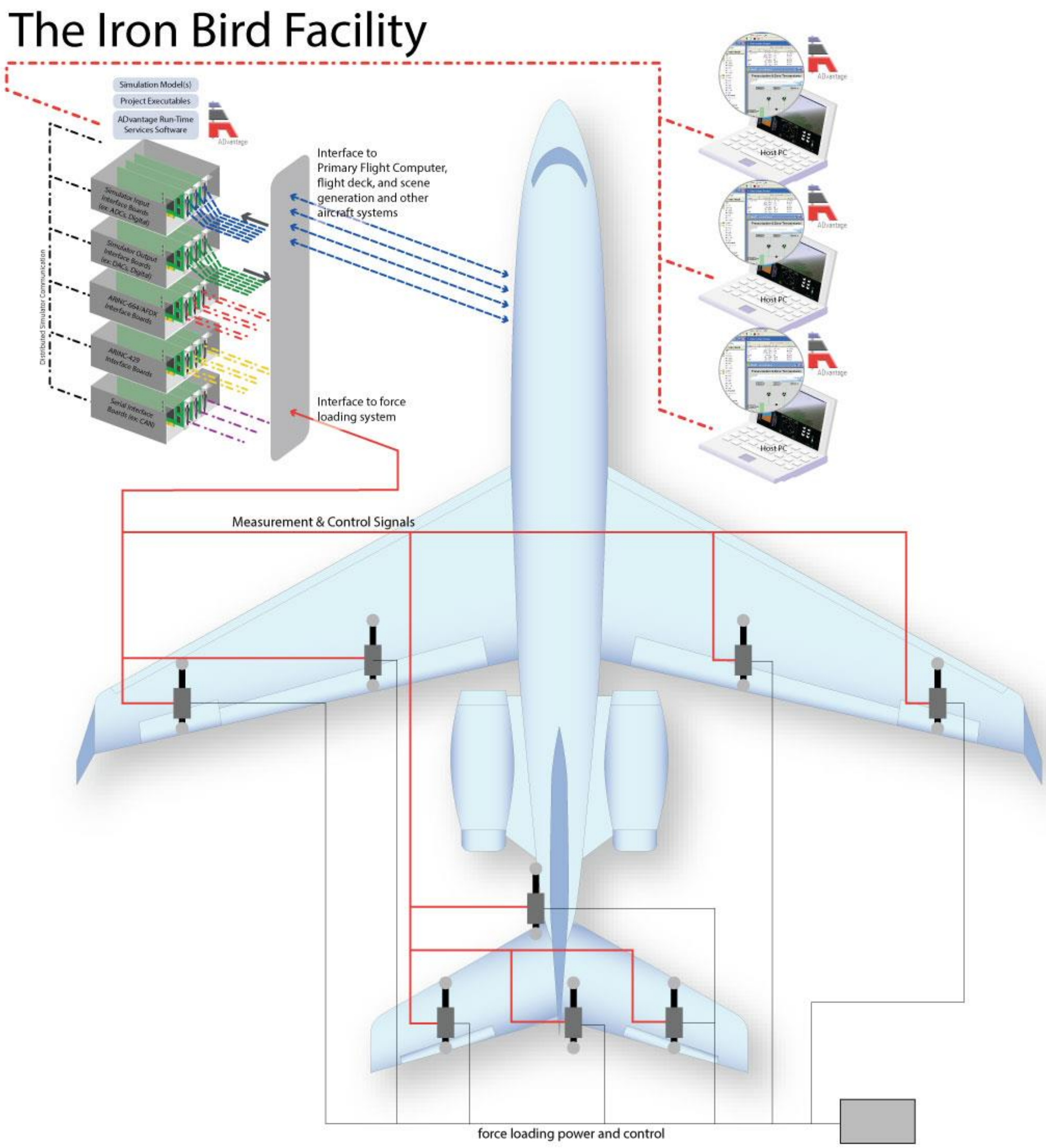
In modern aircraft designs, Fly-by-Wire flight controls actuate the flight control surfaces using electrical and electronic position sensors and actuation signals. These electronically controlled systems include a great deal of intelligence as required to ensure safety during failure conditions and provide additional capabilities not available in conventional cable-driven flight control systems. The Iron Bird facility is used to test the flight control system through a wide range of normal operating and failure-mode conditions without risk of crashing a flight test aircraft. The Iron Bird facility includes real control surface actuators, the associated hydraulic and electrical system components, sensors and drive electronics, the related avionics systems, and more.

Facility Operation

Project development, test execution, test automation, data acquisition, data analysis, report generation, and test evidence archiving are performed with the Iron Bird facility. The Iron Bird facility must include a great deal of flexibility to allow teams to connect from virtually anywhere, receive streaming test data, perform analysis, work collaboratively, and get the job done quickly.

Force Loading

The Iron Bird facility includes a "force loading system" that applies hinge moment forces to the aircraft control surfaces (ex: ailerons, flaps, rudder, etc.) representative of the aerodynamics forces applied during the simulated flight test and driven by the flight simulation model. Mechanical actuators are mounted to the Iron Bird's external structure and apply a load to each control surface under high-fidelity, closed-loop control by the facility's real-time aircraft simulation. Low-latency and real-time determinism in the entire system are of critical importance. If the system under-performs then the test results are invalid.



Cockpit Test Facility

A cockpit integration facility is a simulation based lab test facility that serves many purposes including the development, integration, and verification of cockpit and flight deck systems throughout the aircraft development program. There are two common types of cockpit integration facilities found in the civil and military aircraft industry. Although each aircraft company tends to use different names for these labs, they can be recognized as:

- Cockpit Systems Integration and Verification Lab
- Cockpit Concept Development Lab

Both types of facilities combine real-time simulation of flight dynamics and simulation of many aspects of the aircraft with realistic closed-loop stimulus to the flight deck, pilot controls, and systems included in the cockpit integration facility.

Cockpit Systems Integration and Verification Lab

The cockpit systems integration and verification lab is a facility where real flight deck systems and pilot controls are integrated and placed in a real-time, hardware-in-the-loop environment where the systems are taken through exhaustive and realistic verification testing. Pilot-in-the-loop, and automated (no pilot-in-the-loop) test cases are executed allowing stand-alone behavior and interoperability to be verified against expected behavior during normal and failure-mode flight conditions. Cockpit systems suppliers will participate in many of these test cases to provide the domain expertise required to assess behavior and troubleshoot observed problems.

Cockpit Concept Development Lab

The cockpit concept development lab is a facility where emulated or mock-up flight deck systems and pilot controls are placed in a real-time, hardware-in-the-loop environment for development and assessment with pilot-in-the-loop as part of an aircraft development process. Because the cockpit concept lab does not use real cockpit systems, this facility represents a lower-cost tool for exploring innovative ways of implementing the cockpit (ex: glass cockpit functionality). As the early development tasks are completed, the Cockpit Concept Development Lab can then be repurposed as a tool for aircraft simulation and flight control law development.

Aircraft Simulation Model Development

In addition to developing and testing cockpit concepts and systems, the cockpit integration facilities provide an important tool for developing and validating the real-time aircraft simulation model that is used in all of the simulation based lab test facilities (ex: iron bird, avionics integration facility). During an aircraft development program, virtually every aspects of the aircraft design will evolve. This design evolution results in a continuously evolving real-time aircraft simulation model. As additional modeling detail and fidelity are added to the aircraft simulation model, a new version of the model is issued and must be validated prior to releasing the model for general use. The cockpit integration facility represents the lowest-cost, high-fidelity, pilot-in-the-loop flight simulator and therefore is ideally suited to perform this man-in-the-loop simulation model validation.

Pilot-in-the-Loop Simulated Flight

Pilot-in-the-loop simulated flight is an important tool for tasks such as: Evaluating the handling qualities of an aircraft design and its fly-by-wire flight control laws; getting a sense of the usability of a glass cockpit layout; assessing the convenience of the positioning and layout of flight deck systems. When compared with using a motion-based flight simulator or a flight test aircraft, the cockpit integration facility is a very inexpensive way to submerse a pilot into highly realistic simulated flight test assessment. In order for this pilot-in-the-loop evaluation to be meaningful, the cockpit simulator must operate with high real-time determinism, good repeatability, and low latency.

A low-cost high-fidelity pilot-in-the-loop cockpit simulation facility

Interconnected Simulation Test Labs

Many of the recent and on-going aircraft development programs have added the ability to connect their cockpit integration facilities to other simulation based lab test facilities. For example, the cockpit systems integration lab may be connected, with appropriate cabling and signal switching, to the Iron Bird simulator. With the two facilities disconnected, each facility may be operated as a separate tool for development, integration, and verification. By connecting the two facilities the combination of a cockpit with full flight deck, pilot controls, and avionics modules is added to aircraft hydraulics, electrical power, and control surface actuation focused test facility. This allows the test scope to extend all the way from pilot controls to the actuation of ailerons, flaps, etc., and expands the scope of interoperability testing.

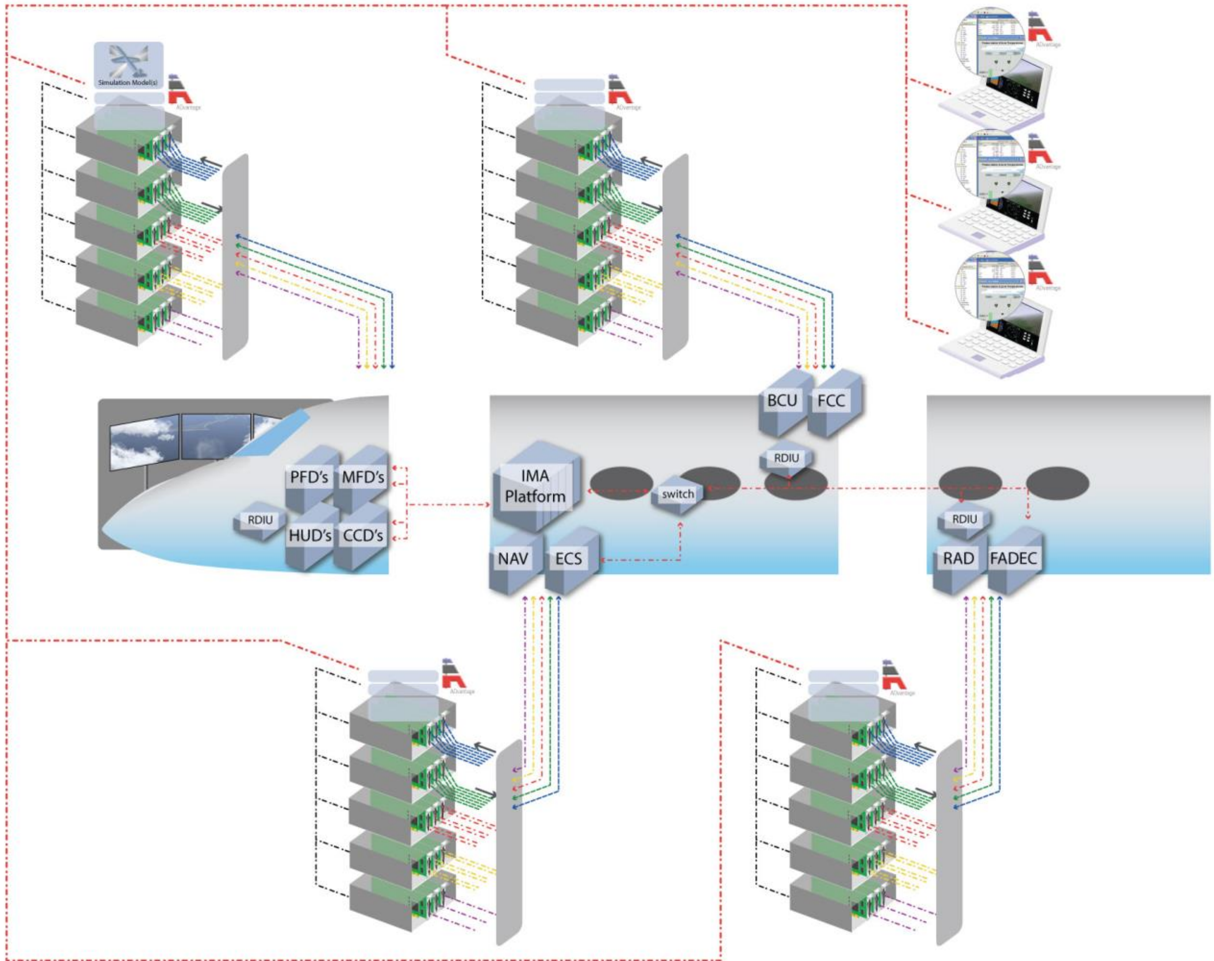
Avionics Integration Facility

The use of electronic systems in new aircraft designs has steadily expanded along with greater interconnectivity and coupling between these systems. Each aircraft subsystem supplier develops and tests their Line Replaceable Unit (LRU) and its mating electronic system(s) through a range of verification tests as part of its development process and as required for airworthiness certification. But it's when all of these complex, interdependent systems are brought together and integrated that many of the design and implementation anomalies and flaws are discovered.

Furthermore, new aircraft designs have added on-board wireless networking for passenger info and entertainment and to support the adoption of Electronic Flight Bag (EFB) capability. Ensuring that these network interfaces are fully secure, and cannot be exploited through some type of hack, is a critical task.

The avionics integration facility provides a powerful, simulation-based tool that is used to integrate and test these aircraft subsystems with lower cost and no risk of damaging a flight test aircraft in the process and provides the ideal platform for assessing and evaluating aircraft cybersecurity.

The Avionics Integration Facility



Support the Flight Test Program

The flight test program involves using some number of highly-instrumented prototype aircraft to fly an exhaustive series of test flights. During the execution of these test cases, unexpected behavior is inevitably observed. The avionics integration facility is put to work as a tool for repeating and investigating the unexpected behavior discovered during test flights. The specific conditions that resulted in the error may be replayed and the source of the problem can be determined. The problematic test case may be run again and again until the root of the problem is found. The avionics integration facilities typically offer better visibility into the internal workings of each of the aircraft subsystems and as a result allow for easier and lower-cost troubleshooting.

Out-the-Window Display

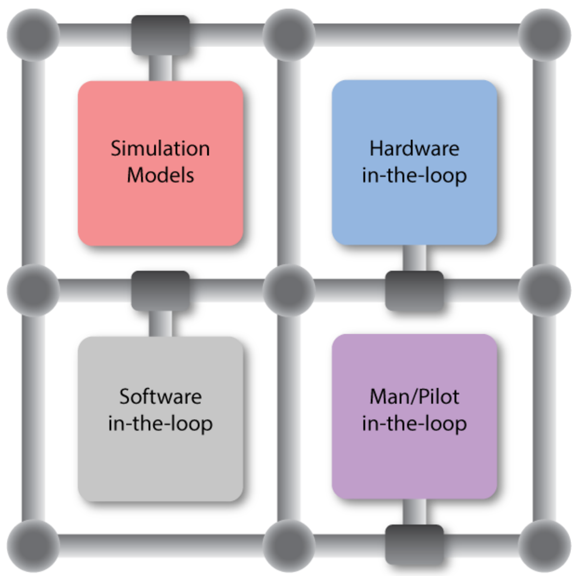
An out-the-window visual scene generation system is typically used to provide the test pilot with realistic situational awareness. Scene generation systems include high-fidelity 3D animation, airport and runway modeling, and ground elevation. During simulated flight, the elevation above the ground will be determined by the out-the-window scene generation system and transmitted to the aircraft flight dynamics model. Latitude and longitude position, altitude, pitch, roll, yaw, and velocities are fed by the real-time flight dynamics simulation to the scene generation system, allowing the correct visual representation to be displayed.

Network Communication Testing

With more and more electronic systems in an aircraft, collecting data from more and more sensors, and sharing this data with other electronic systems, serial communication using digital networks throughout the aircraft is unavoidable. The ARINC-429 network databus commonly found in civil aircraft and the MIL-STD-1553 network databus found in military aircraft are nothing new but new aircraft designs are using more and more channels of these traditional networks. In addition to this older technology, low-cost Ethernet network technology has found its way into the aircraft in ARINC-664 or AFDX. ARINC-664 uses a cascaded star network topology, sophisticated network switches, and dual-redundant lines to provide determinism and fault-tolerant communication, as opposed to the not-so-deterministic communication offered with the TCP/IP Ethernet found in garden-variety LANs. ARINC-664 offers network transmission speeds up to 1000x faster than ARINC-429 and can move far more information over a single cable link. Verifying and validating this aircraft network communication is an important task for the avionics integration facility.

Model Based Test Framework

A Test Framework is a set of computer equipment and software used to perform MBSE verification testing. A test framework may include a single aircraft component or a full system of aircraft systems, interconnected and operating through a limitless set of flight tests. A well-designed simulation based aircraft testing facility makes it easy to define as many Test Framework projects as needed. This allows the facility to be used with numerous different sets of devices-under-test, referred to as "Test Subjects" in common MBSE verification lingo. A Test Framework project represents one configuration for a simulation based test facility and will include some or all of: simulation models, hardware, software, man or pilot. The Test Framework defines the collections of test subjects included in a framework and allows one or more test cases to be performed on the framework. The illustration below provides a conceptual view of the Test Framework.

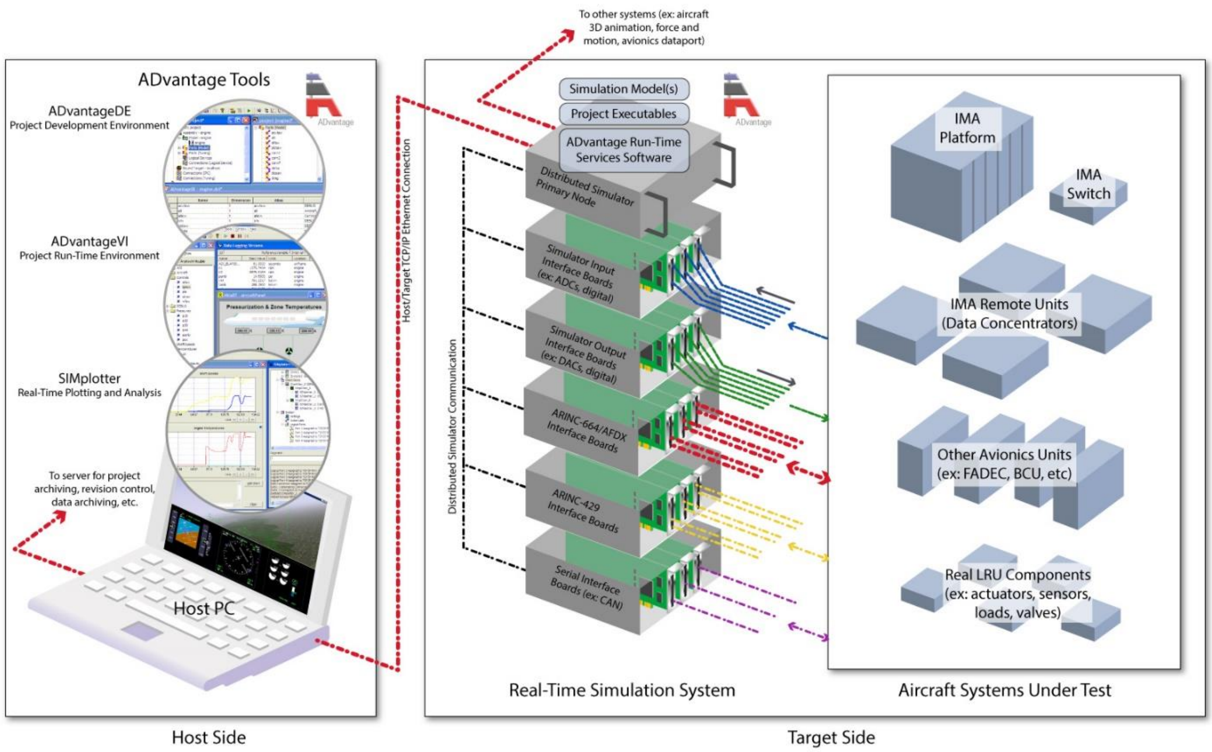


MBSE Test Framework

Test subjects are connected to one another through software, analog and digital interfaces, power interfaces (ex: mechanical, hydraulic, pneumatic, etc.), and human interfaces in a manner identical to the systems interface connections in the real aircraft.

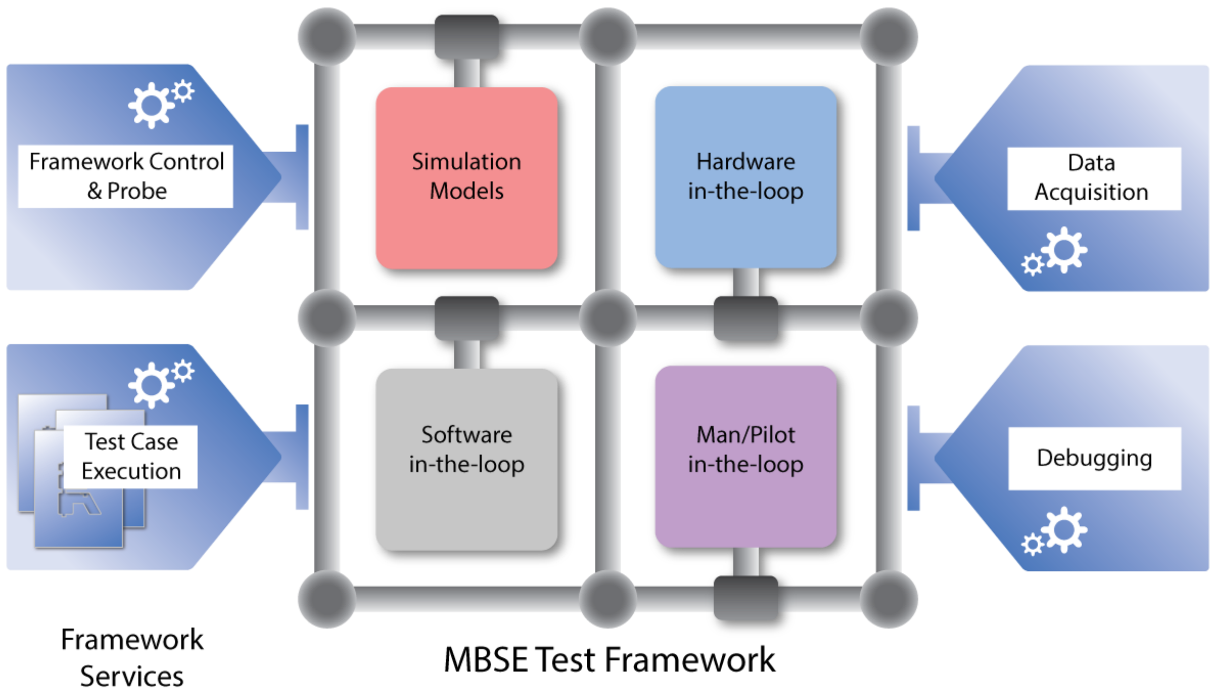
It's common to see dozens and even hundreds of different Framework Project be assembled for a single simulation based test facility, for a single aircraft program. Some number of test cases are executed with each Framework Project, test results are generated, results are analyzed, and test evidence is archived. Tests are run on a Test Framework using a set of Framework Services and their associated application software.

Real-time test facilities (i.e. hardware-in-the-loop or man-in-the-loop) are largely made up of a set of computers running a Real-Time Operating System (RTOS), containing a collection of I/O interface boards, and sometimes interfaced with power hardware (ex: electrical, hydraulic, pneumatic, etc). The figure below illustrates a real-time test facility. The facility's "target side" operates in real-time at an appropriate frequency or set of multi-frequency rates. Application software running on standard desktop computers connect with the test facility and provide a full range of capability for performing tests, automating tests, collecting data, visualizing test results, and generating test evidence.



Framework Run-Time Services

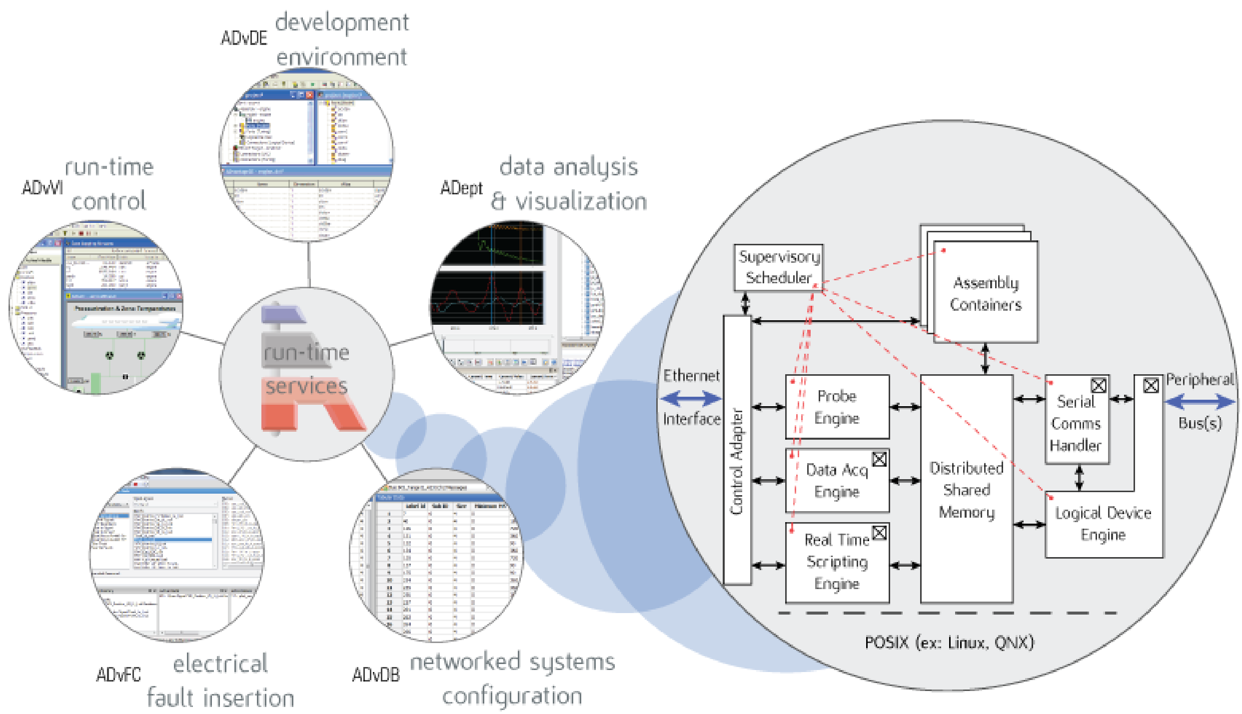
The Framework Project is loaded on either a real-time computer running an RTOS or a general purpose computer (typically running Windows or Linux) where it is utilized to run through one or more test cases. Test case execution is performed using a set of software services referred to as "framework services". The figure below provides a conceptual view of the MBSE Test Framework Project with Framework Run-Time Services connected.



The set of Framework Run-Time Services includes:

- Data acquisition and streaming – time-stamped data logging from any area of the Framework Project (ex: simulation signals, analog and digital signals, databus network traffic, memory mapping from within aircraft electronic systems)
- Framework control – start, stop, pause of simulation operation
- Framework probe – getting and setting Framework variable values
- Real-time scripting – time deterministic and repeatable test case execution
- I/O handling – read and write of signal values to digital and analog interfaces
- Serial and databus handling – scheduling, sending, receiving, packing, and unpacking of network data
- Framework process scheduling – execution of supervisory, distributed sync, model execution, data acquisition, and I/O handling service processes

The figure below illustrates the Test Framework Run-Time Services connected to the application software tools used to work with a Test Framework Project.

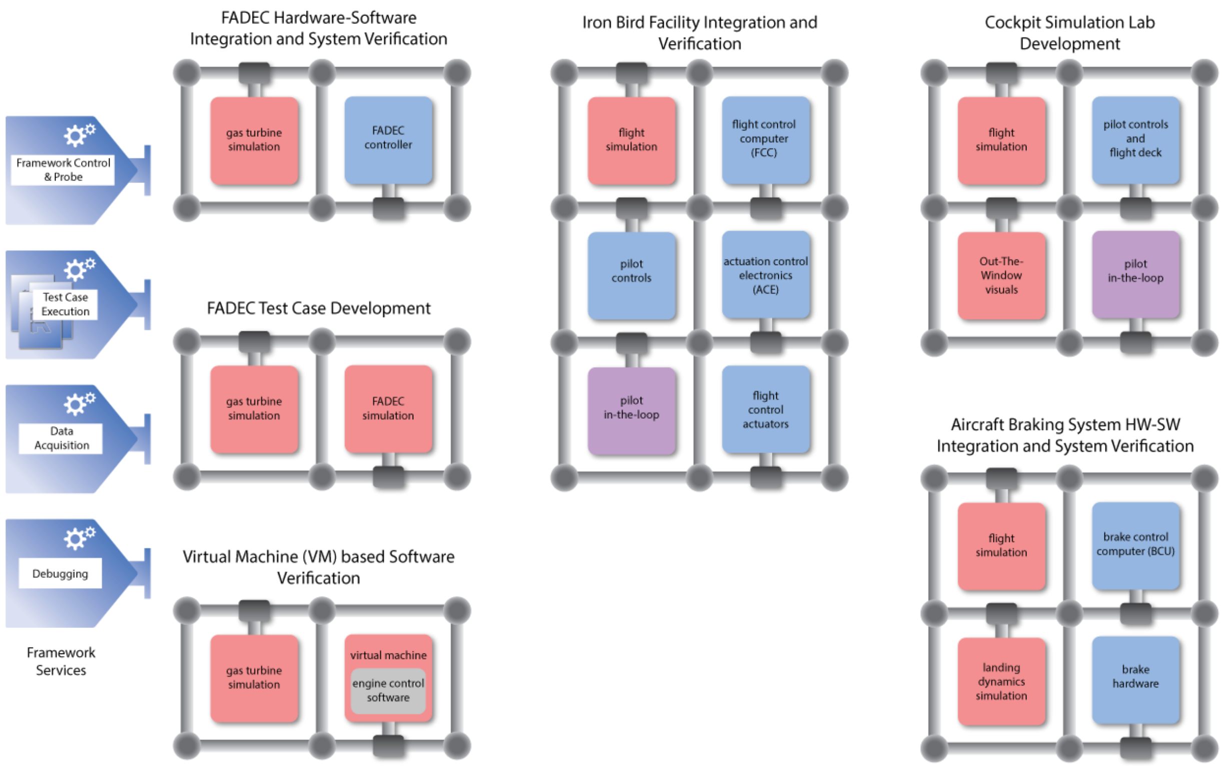


Example Test Framework Projects

Some example Test Framework Projects used for the development of different aircraft systems or complete aircraft at different stages of the program include:

- FADEC hardware-software integration systems verification project – includes a gas turbine engine simulation model, connected to a real Electronic Engine Controller (EEC), for development of a specific engine
- FADEC test case development project – a gas turbine engine model connected to a simulated EEC simulation, used to develop test cases with need to utilize an expensive test rig or a real EEC
- FADEC VM-based software testing project – a gas turbine engine simulation model is connected to a Virtual Machine (VM) implementation of the EEC, running real airborne software, to perform dynamic software verification testing
- Iron Bird facility project – flight simulation model connected with the Flight Control Computer (FCC), the Actuation Control Electronics (ACE), flight control actuators, aircraft hydraulic system, pilot controls, with pilot-in-the-loop
- Cockpit simulation project – flight simulation, Out-The-Window (OTW) visuals display, pilot controls, flight deck, connected with pilot-in-the-loop
- Aircraft braking system verification – flight simulation connected to a real Brake Control Unit (BCU), real brake hardware (hydraulics, brakes, valves, etc.) and landing dynamics simulation

The figure below provides a conceptual view of the different examples of Test Framework Projects.



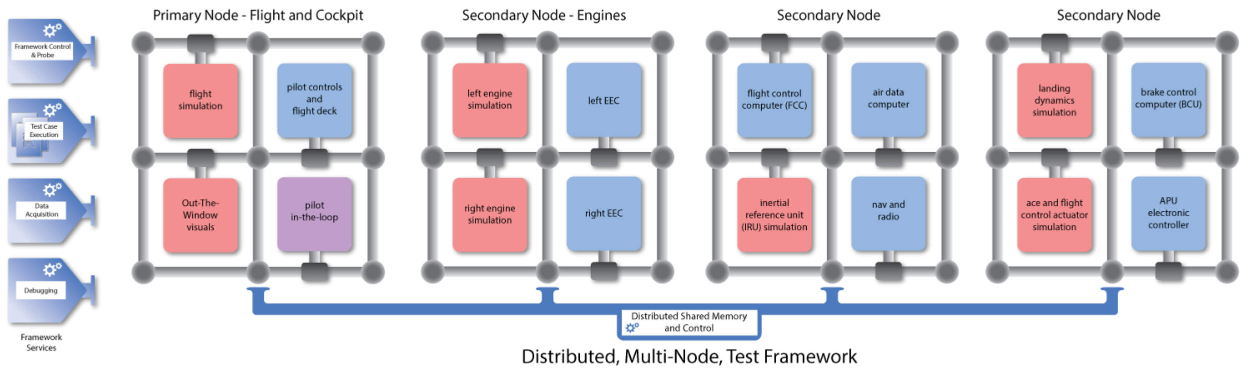
In the development of a given aircraft system, they will commonly be dozens of different Framework Projects used to test at different stages of the development program. For full aircraft integration facilities (ex: iron bird, avionics facility, cockpit facility), different Test Framework Projects are used to enable testing to be performed with only the subset of real aircraft systems available as required to achieve a specific set of verification testing objectives.

Distributed Test Framework Project

Large test facilities can include thousands and even tens of thousands of channels of digital, analog and databus signals. The computational resources required to handle all these signals and execute some set of simulation models requires the use of multiple computers.

Standard, rack-mounted PCs combined with commercial or open source real-time operating systems are ideally suited to provide any lab or industrial environment simulation facilities computation resources. I/O interfaces are included using Commercial-Off-The-Shelf (COTS) computer boards from popular vendors (ex: National Instruments, Ballard Technologies). Large facilities are implemented using a distributed real-time simulation verification architecture. A well-implemented MBSE verification software framework will make it easy to build distributed simulation projects with any number of PC-based simulation computers operating as a massive parallel computing machine, and easily controlled from a single host PC.

Distributed real-time verification projects communicate with one another through a distributed shared memory and control backbone.



Distributed, Multi-Node, Test Framework

The figure above provides a conceptual illustration of a distributed, multi-node Test Framework Project.

Model Based Verification Process

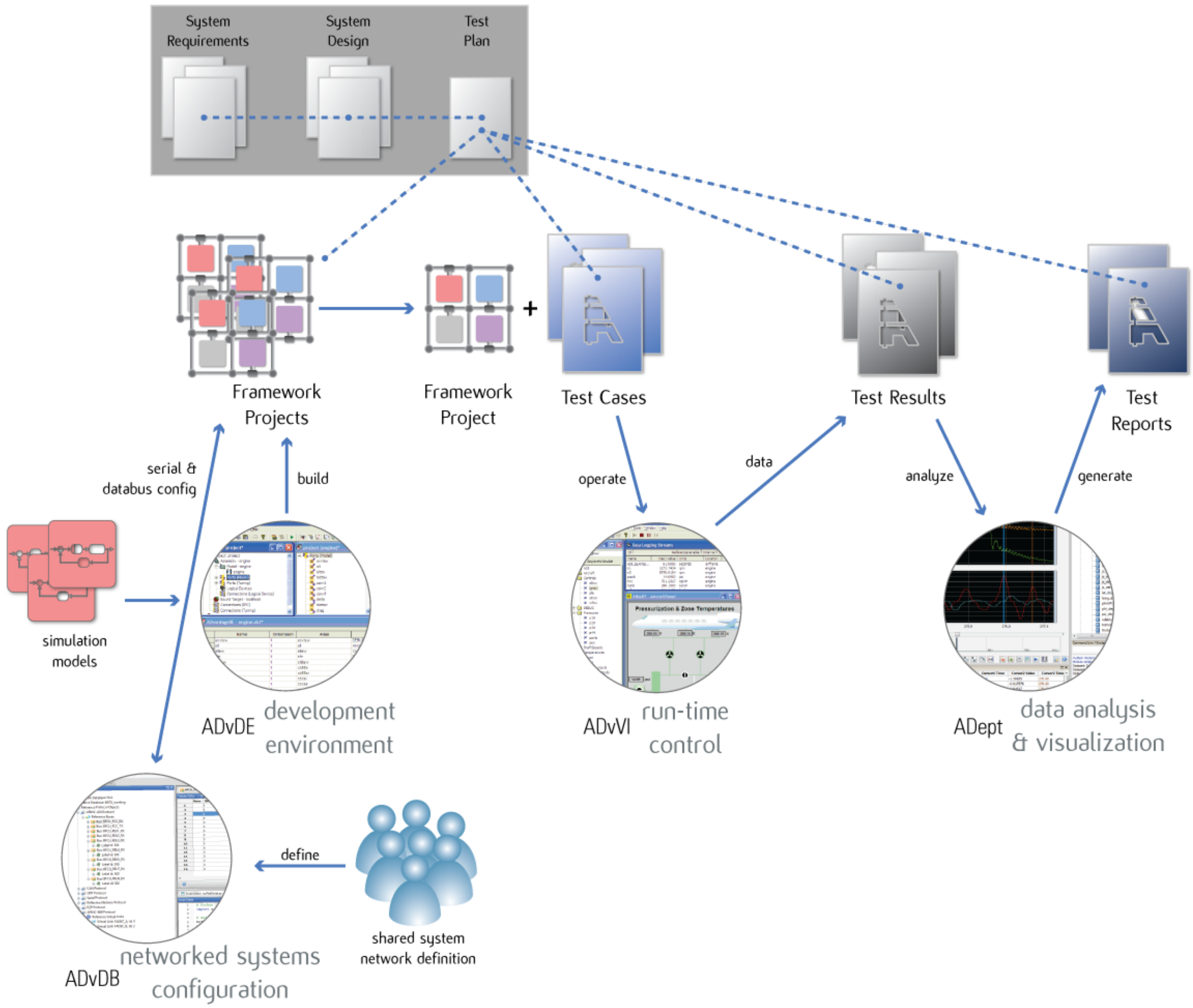
A model based verification process is a very complex component of a sophisticated products company with many arms and legs to manage. When a new product development project is launched, system requirements are defined, the system design is taken through to maturity, and the verification process is performed. A standard five-step verification process involves:

1. High level planning to determine the test facilities and test subjects required to perform the verification effort
2. Test strategy identification where each system requirement is assigned to a test facility with a general testing approach
3. A collection of test cases is assembled for each facility, in order to test against every system requirement, ideally in a manner that optimizes the use of facilities, test subjects, and domain experts
4. Tests are executed, results are collected, and issues are investigated
5. Results are analyzed and testing evidence is prepared

Within this five-step model based verification process there are a number of different artifacts that are developed, delivered by suppliers and other teams, revision-tracked, archived, and submitted during certification audits. Artifacts of the MBSE verification process include:

- Simulation models – source models, code models, and model binaries
- Test Framework Projects – compiled, executable framework processes and configuration files
- Test Cases – automated and/or pilot-in-the-loop test cases that include data acquisition configurations and real-time (repeatable) scripted perturbation
- Test Results – time-stamp and annotated data with traceability embedded
- Test Reports – reduction and compilation of test data, formatted for submissions

- Traceability Matrix – traceability from system requirements, to system design, test plan, simulation models, framework projects, test cases, test results, and test reports



The figure above illustrates the various artifacts and the collection of tools used to create and work with these artifacts.

Integrated Modular Avionics Simulation Based Facility

Integrated Modular Avionics (IMA) is forever changing commercial and military avionics systems. IMA, and its early adopters have rewritten the rules of integration, verification, and certification for modern avionics systems.

The Airbus A380 and the Boeing 787, are two highly advanced aircraft programs embracing an IMA platform architecture. Both Boeing and Airbus are banking on IMA to improve their competitiveness.

The Airbus A350XWB as well as a collection of yet-to-be-announced aircraft programs are committed to IMA.

After decades of methodical, evolutionary changes, the top aerospace competitors, under intense market pressures, have retired the status quo. Multidisciplinary optimization efforts are yielding major changes in aircraft design and technology. Along with composite materials, advanced propulsion systems, novel airfoil designs, etc., IMA is a major technological undertaking designed to improve efficiency and maintainability on multiple levels. Unsurprisingly, IMA is making a significant impact on R&D, which must rise to the challenge.

IMA includes the following key elements:

- A distributed architecture where avionics functions are split into centrally computed software applications and remotely located End Systems
- An “IMA Platform” providing shared computational resource to execute avionics application software
- A shared, dual-redundant ARINC-664/AFDX network

With few exceptions, having aircraft system suppliers develop software applications for a shared, third-party airborne computer system is a big departure from past practices. But this is exactly what IMA requires.

As aircraft systems’ dependence on software, electronics, and data sharing with other systems increases, so has the challenge of integration and verification. In an IMA-based aircraft this task is suddenly far more challenging. Today’s program schedules are more aggressive than ever. To support these short schedules, system integration and verification depends on MBSE techniques.

MBSE Techniques for IMA Integration

IMA-based programs introduce a new role: The IMA Manager. The IMA Manager, or management team takes responsibility for the allocation of the IMA’s shared resources. The IMA Platform (ARINC-653 in particular) and the ARINC-664 network rely heavily on XML to specify shared-resource configurations. Some uses for XML configuration tables are:

- ARINC-653 inter-application communication specification
- ARINC-653 partition and module specification
- Allocation of applications on ARINC-653 partitions
- ARINC-664 switch configuration

The IMA Management team is responsible for:

- Allocating IMA platform resources
- Managing IMA platform configuration tables
- Performing verification testing on the integrated platform
- Qualifying the module configuration

The IMA management team does integration testing at multiple levels including:

- Desktop software testing of the application
- Application testing on a representative hardware platform
- Functional verification on the real IMA platform
- Integration of all applications with an IMA integration facility
- Functional verification of individual systems within the IMA Platform
- Integration and verification of all systems together

This work demands a new category of hardware-in-the-loop (HIL) simulation testing facilities dedicated to the task of integrating and verifying the common core avionics shared computational resource, the data concentrator network, and the avionics control application. This new type of facility relies heavily on a flexible real-time verification software framework with rapid re-configurability, and distributed architecture.

Aircraft Power Hardware Simulation Based Facility

Over the past decade, the aircraft industry has converged on a shared vision for the future of aircraft power systems. This vision represents a dramatic shift away from various types of power found in traditional aircraft and offers a wide range of benefits for tomorrow's commercial and military aircraft.

The non-propulsive power systems in traditional aircraft are typically driven by a combination of different secondary power types including: hydraulic, pneumatic, electrical and mechanical power. All power is extracted from the aircraft engines. Hydraulic power is provided using hydraulic pumps driven by mechanical rotation sourced from the engine gearbox and is distributed to power various aircraft systems including flight control actuators, aircraft braking, landing gear extension/retraction, and door closure. Pneumatic power is extracted from the engine, using software controlled bleed valves, and is used to power the aircraft Environmental Control System (ECS) and wing anti-icing. Mechanical power from the engine gearbox also drives lubrication and fuel pumps and electrical power contributes to the capability of nearly every aircraft system in modern aircraft that make increasing use of airborne software controlled electronic systems.

The market demand for more energy efficient aircraft is driven by many stakeholders including airline operators, legislators, and public opinion. In the meantime, power electronics technology has made tremendous breakthroughs over the past decade in areas including electromechanical actuators (EMA), electro-hydrostatic actuators (EHA), fault-tolerant electric motor/generators, and power converters. This forward-leap of technology creates a viable path, fueled by economic gain, for replacing many and potentially all of the hydraulic, pneumatic, a mechanically powered non-propulsive systems with electrically powered systems [2-25] to design a More Electric Aircraft (MEA).

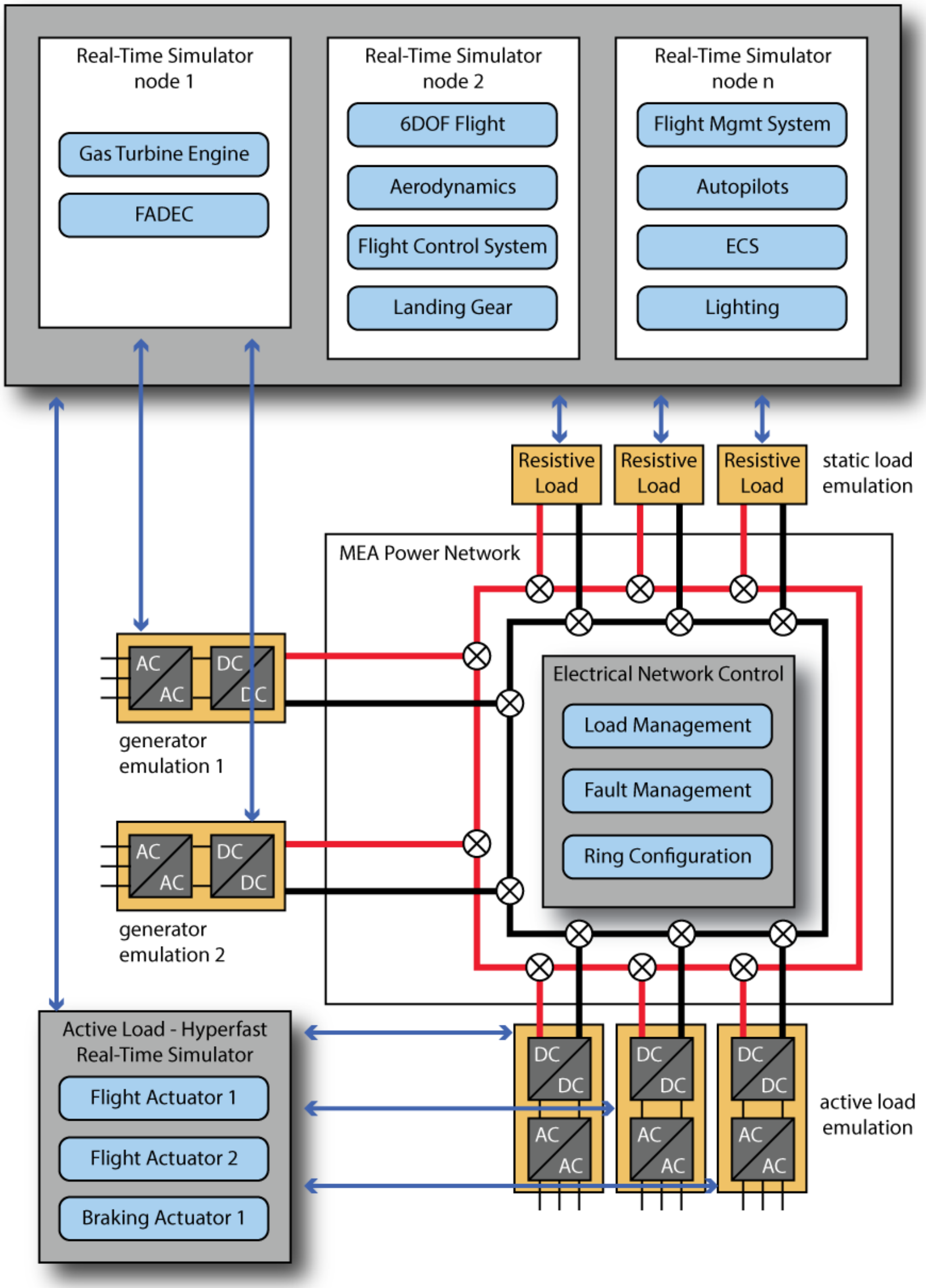
Industry has recently achieved general agreement on key elements of the MEA. For example, industry is now focusing on technology based on a high-voltage DC power distribution architectures with 270VDC distribution emerging as the most popular approach [2,4-8]. However, optimizing aircraft power systems technology to support a 270VDC distribution system, including generation, distribution topology, power conversion, and the design of specific MEA systems, is a complex effort. There is a high-level of dependency and interaction between the various systems in a given MEA design with complex and fast dynamics. There is a wide range of technology that must be refined and optimized within the context of a single aircraft design in order to achieve the cost reduction goals for the MEA. These challenges give rise to a capability requirement; a requirement for a flexible MEA development platform that can accelerate the pace of development of MEA technology.

This MEA Power Systems development and testing solution relies on MBSE methodologies and technology that have evolved rapidly over the past two decades and draws on MBSE technology in the area of power systems and power electronics. The MEA Power System Development Facility enables technology concepts and prototypes to be tested as pure simulation in closed-loop with real aircraft power systems, operating with representative electrical behavior, and evaluated through normal and failure mode flight conditions. This facility includes:

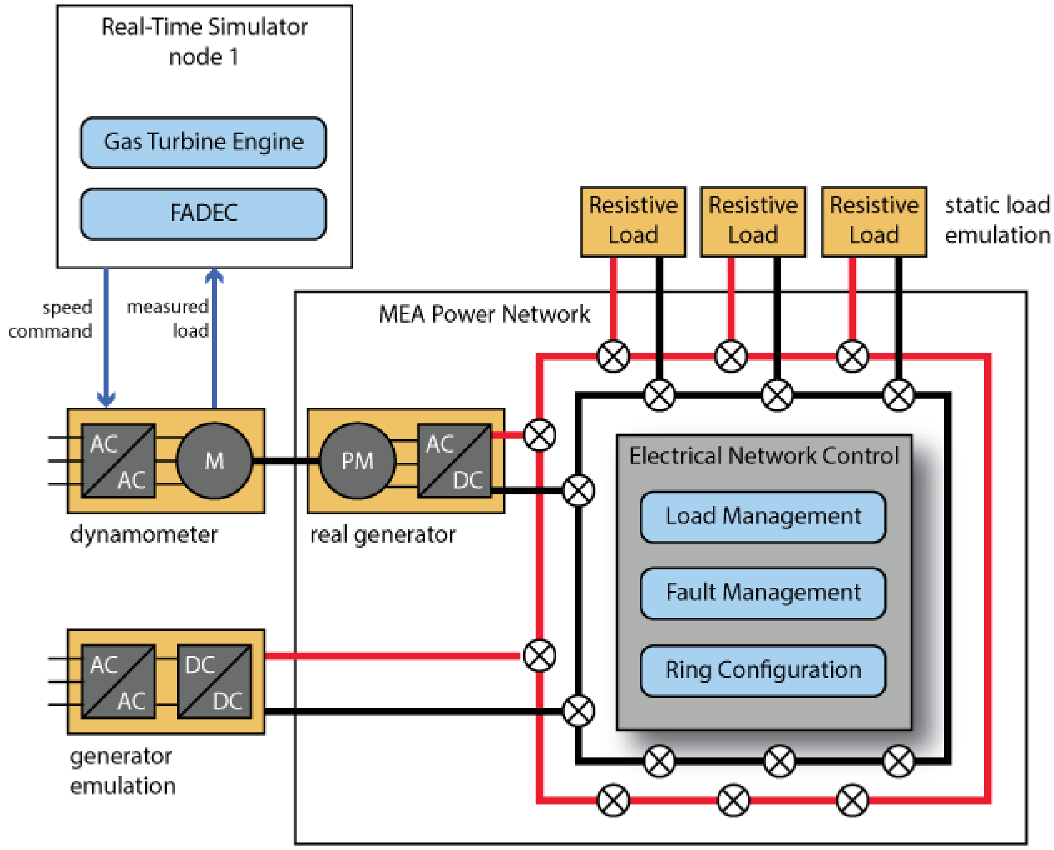
- real-time simulation controlled dynamometer enabling rotational forces and angular velocities to be applied to real starter/generators with simulated gas turbine engine dynamics providing highly realistic operating behavior
- AC-DC power equipment capable of converting high power generator output to high-voltage DC as required in MEA designs
- An active load system capable of sinking aircraft DC bus power with high-fidelity current and voltage dynamics controlled in closed-loop with electromechanical flight control actuator simulation
- 6-degrees-of-freedom real-time simulated flight with high-fidelity simulation of aerodynamics and electromechanical flight control actuators

The figure below illustrates the MEA Power Systems Development facility.

MEA Power System Development Facility



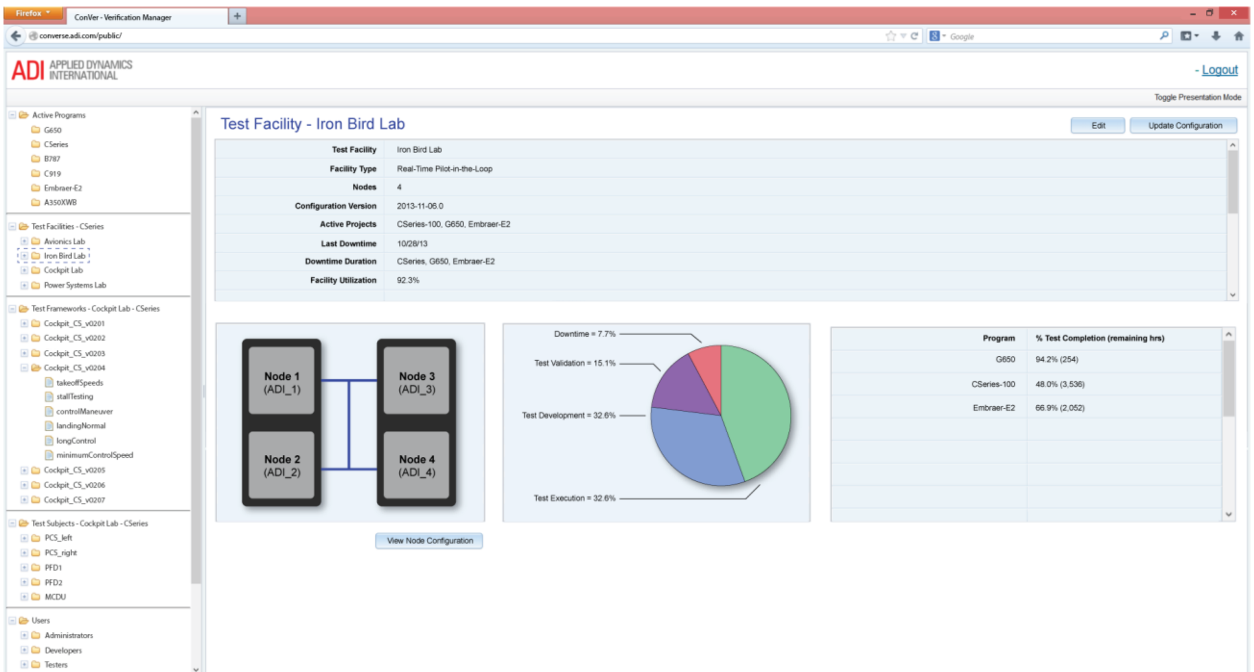
Power electronic equipment is used to emulate the engine-driven generators during normal operation. Alternatively, real generators may be placed in-the-loop to evaluate new generator concepts and their interaction with the rest of the More Electric Aircraft power system. The figure below shows the MEA Power System Development facility with a generator in-the-loop interfaced with real-time simulation of the gas turbine engine and FADEC.



The MEA Power Systems Development facility is used to develop, evaluate, and test a wide range of new aircraft power systems including flight control actuators, converters, generators, fault protection equipment, and aircraft loads.

Business Intelligence for MBSE Verification

Business Intelligence (BI) is an increasingly popular set of methodologies, architectures, and technologies used to instrument and manage a business with multi-dimensional business-wide optimization. BI includes reporting, analytics, data acquisition and streaming, statistical methods, metrics and optimization, version control, process management, and visual dashboards. The MBSE verification process is large, complex, unwieldy, and hard to control. The implementation of a BI system to provide control over the MBSE verification process involves designing a process that works within the existing PLM structure of an organization but add visibility into operation and the ability to identify problems early in the short product lifecycle.



Applied Dynamics has designed, and implemented with various product organizations, the Converse System for MBSE Verification Process Business Intelligence. Converse is a web-based system that is to MBSE Verification what the Enterprise Resource Planning (ERP) system is to the areas of inventory, vendor management, bill-of-material, job order, accounting, and HR areas of a product business. The investment in simulation based aircraft testing software, systems, and IT infrastructure, such as the Converse System, has offered significant returns and has resulted in risk mitigation, reduced loss of life, less flight testing, and brings new technologies into the products much quicker than previous processes.

Summary

The engineering and technology space surrounding Model Based Systems Engineering has been growing in scope and importance for product development companies, for at least a couple decades. Product Lifecycle Management (PLM) methodologies allow product companies to shorten development cycles, reduce cost, and refine the product offering to enable each successive version to be better, cheaper, faster. Matlab/Simulink has become the Microsoft Word of technical computing and the leading format for designing and simulating product behavior.

In the decade from 2000 to 2010, a tremendous amount of technology advancement was seen using Simulink models to design a system, and use Simulink-interfaced code generators to output C code providing the behavioral capability associated with any intelligent subsystems within the designed system. This, along with other advancements in MBSE, has allows for the more and more complexity to be designed into a system while at the same time reducing product design cycles. Added complexity to provide a larger feature set, reduce energy consumption, reduce initial and maintenance costs, improved user experience, etc. have expanded the effort associated with the system verification tasks. More and more work is being placed on the systems verification team whose role is to ensure the product does exactly what it was designed to do, and nothing else.

The MBSE world is seeing an increased investment in model based systems verification teams, facilities, software, and business process to expand what is, for many product companies, a bottleneck in their PLM business operations.

Aircraft manufacturing involves product certification and rigorous PLM methods. The certification of an aircraft requires that each aircraft system be tested to ensure they meet all system requirements, and meet system-specific airworthiness standards. Then systems must be integrated as incomplete and complete sets to be verification tested ahead of the Flight Test. The Flight Test Program represents the final system integration testing effort. Model based verification involves testing one or more systems interfaced with simulation in order to put the system(s) through normal and failure mode conditions that are highly representative of the complete aircraft behavior.

This activity involves a wide range of artifacts including simulation models, requirements documents, design documents, traceability matrices, test framework projects, facilities, product domain experts, test cases, verification software, real-time computer systems, and prototype aircraft systems. Each of these artifacts is being refined and is evolving through the product lifecycle. This results in a challenging management tasks in order to perform model based system verification in a timely and cost-effective manner.

The investment in simulation based aircraft testing software, systems, and IT infrastructure, such as the Converse System, has offered significant returns and has resulted in risk mitigation, reduced loss of life, less flight test time, and brings new technologies into the products much quicker than previous processes.

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