



AEROSPACE INFORMATION REPORT

AIR6326™

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Aircraft Electrical Power Systems
Modeling and Simulation Definitions

RATIONALE

This document establishes basic terms and definitions applicable for modeling and simulation of aircraft electric power systems. It lays the foundation for a series of AIRs and ARPs within the scope of the SAE AE-7M committee.

AIR6326 has been reaffirmed to comply with the SAE Five-Year Review policy.

INTRODUCTION

Background:

The development of more- and all-electric aircraft (MEA, AEA) concepts for future-generation commercial and military airplanes has significantly impacted aircraft electric power system (EPS) design. Many functions that are conventionally managed by hydraulic, pneumatic and mechanical power are being replaced by electric power aiming to reduce overall aircraft weight and size, improve fuel efficiency and reduce environmental impact. On the other hand, this transition has resulted in a substantial increase in the number of onboard electrical loads typically driven by power electronic converters (PEC) and motor drives, e.g., for such functions as pumping fuel, cabin pressurization and conditioning, engine start, flight controls, landing gear actuation, and many others.

Developing the EPS architectural bus paradigm for the next generation of aircrafts (more- and all-electric) involves extensive modeling and simulation (M&S) activities to ensure, prior to the physical implementation, the proper operation of the entire EPS, including its integrity and the quality of electric power delivered to various loads under different flight scenarios. Since the number of PEC-driven loads in an on-board power system can be on the order of dozens or even hundreds, the development of accurate and computational time-saving simulation models are of great importance.

EPS simulation studies are required to address the following:

- EPS sizing and power budgeting (generation and off-take)
- Assessment and benchmarking of EPS weight, cost, efficiency and reliability
- Power flow
- Cabling arrangements
- EPS control logic, events and reconfigurations according to flight scenario and in response to faults
- Electric power quality: transient responses, in-rush effects, ac harmonic content and dc ripple
- EPS stability margins and integrity

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Documents
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A significant penetration of electrical power processed by PEC leads to new challenges in addressing these and other EPS-related issues both in a hardware and modeling environment. These challenges arise both from system complexity and from the fact that PEC systems feature a wide range of dynamic time constants: system time constants may be in the order of seconds while power electronic events occur at the nanosecond to microsecond level. This can place severe demands on computer resources and computation time.

Summarizing, fundamental changes to modern aircraft EPS are currently underway and the role of M&S in the development of cutting edge EPS is more crucial than ever before. There is a need to establish an EPS-specific M&S common framework that will ensure effective and accurate solutions to the problems that arise. This will provide good co-ordination in terminology and approaches used by different companies/institutions. This document opens a series of AE-7M M&S documents specific for aircraft EPS aiming to establish such a framework.

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1. SCOPE

The objective of this document is to define basic terms and definitions and to provide general guidance for M&S of aircraft EPS.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

1. Moir, I. and Seabridge, A., "Aircraft systems: Mechanical, electrical, and avionics subsystems integration", John Wiley & Sons, 2008.
2. Bozhko, S.V., Wu, T., Hill, C., and Asher, G.M., "Accelerated Simulation of Complex Aircraft Electrical Power System under Normal and Faulty Operational Scenarios" - IECON 2010: 36th Annual Conference of the IEEE Industrial Electronics Society, Phoenix, AZ, November 2010.
3. Kuhn, M., Otter, M., and Raulin, L., "A Multi Level Approach for Aircraft Electrical Systems Design" - 6th International Modelica Conference, Bielefeld, Germany, March, 2008.
4. Wu, T., Bozhko, S.V., and Asher, G.M., "Accelerated Functional Modeling of Aircraft Electrical Power Systems including Fault Scenarios" - IECON 2009: 35th Annual Conference of the IEEE Industrial Electronics Society, Porto, Portugal, November 2009, Vol. 1-6: 2395-2402.
5. Saber® Simulator Guide. Reference Manual, SYNOPSYS 2006.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

2.2.1 NASA STD 7009 "Standard for Modeling and Simulations"

NASA STD 7009 provides engineering and technical requirements used in NASA programs and projects for M&S processes, procedures, practices, and methods. This standard describes the major stages of M&S activities such as development, execution, as well as analysis and presentation of the results achieved.

2.2.2 IEEE Std 1516 - 2010 "Standard for Modeling and Simulation High Level Architecture - Framework and Rules"

IEEE Std 1516 defines the framework and rules of High Level Architecture (HLA) for distributed M&S of complex systems and their components to ensure a consistent implementation. The standards contained in HLA may differ; however they are interrelated and need to be considered as a product set. The HLA is an integrated approach that has been developed to provide a common architecture for simulation.

2.2.3 ARP4754 Rev. A "Guidelines for Development of Civil Aircraft and Systems"

ARP4754 addresses the process of aircraft systems development taking into account the overall aircraft operating environment and functions. This includes validation of requirements and verification of the design implementation for certification and product assurance.

2.2.4 EIA Standard EIA-632 "Processes for Engineering a System"

EIA-632 describes ways of engineering and producing quality systems and focuses on conceptualizing, creating and realizing a system and the products that constitute it. The standard is applicable across all industry sectors and technology domains, describing the essential features of the engineering practices.

2.2.5 MATHWORKS Automotive Advisory Board (MAAB) "Control Algorithm Modeling Guidelines Using MATLAB®, Simulink® and Stateflow®"

In the subject document, MAAB sets guidelines for using Mathworks products to achieve successful M&S projects and can be very useful for the developers using other platforms as well. Many aspects are covered, including system integration, model interfacing, code and documentation writing, model reuse and exchange and others aiming for effective M&S process.

2.2.6 MIL-STD-3022 "Documentation of Verification, Validation and Accreditation (VV&A) for Models and Simulations"

MIL-STD-3022 provides templates that facilitate consistent documentation of M&S verification, validation and accreditation processes and promotes a common framework and interfacing capability that can be shared within and/or between the M&S programs.

2.2.7 NASA Orion GN&C MATLAB/Simulink Standards

This NASA document describes the standards and guidelines employed by the NASA Orion Crew Exploration Vehicle Flight Dynamic Team while developing Guidance, Navigation and Control (GN&C) algorithms in MATLAB/Simulink.

2.2.8 SAE Surface Vehicle Standard J2546 "Model Specification Process Standard"

SAE J2546 establishes a common set of standards in defining modeling requirements for automotive electrical, electronic and mechatronic components. It provides guidance for specifying analysis requirements, model assumptions, model fidelity, model architecture, validation requirements, and deliverables for electrical and electronic components, as well as the integral interfacing systems (mechanical, thermal, hydraulic) associated with them.

2.2.9 Bozhko, S., Yang, T., Asher, G., and Wheeler, P., "Advanced Techniques for Accelerated Simulation Studies of Complex Aircraft Electrical Power Systems," SAE Technical Paper 2011-01-2623, 2011, doi:10.4271/2011-01-2623.

This technical paper introduces a multi-level modeling paradigm and demonstrates its application for effective simulation studies of complex aircraft EPS under different flight scenarios.

2.3 Glossary

AEA	all-electric aircraft
AC ESS	ac essential bus
ATRU	autotransformer-rectifier unit
CIL	controller-in-the-loop
ECS	environmental control system
EMA	electromechanical actuator
EMC	electromagnetic compatibility
EPS	electric power system
GCU	generator control unit

HIL	hardware-in-the-loop
HVDC	high voltage dc bus
MAAB	Mathworks Automotive Advisory Board
MEA	more-electric aircraft
MOET	More-Open Electric Technologies (European FP6 Program)
M&S	modeling and simulation
PEC	power electronic converter
PIL	processor-in-the-loop
PWM	pulse width modulated
SIL	software-in-the-loop
WIPS	wing ice protection system
xHIL	experimental HIL

2.4 Basic Terms and Definitions

This section summarizes the most common terms and definitions that are relevant for M&S activities in the field of aircraft EPS.

MODEL: A model is a conceptual representation of (some aspects of) a phenomenon in question.

MODELING: This is the process of generating a model.

SIMULATION: This is the process of executing a model. Simulation brings a model to life and provides insight into how the modeled object/phenomena will behave. A software simulation uses a computing system to execute a model.

NUMERICAL INTEGRATION METHODS: These are methods for numerically solving differential equations, or algorithms for calculating numerical values of definite integrals.

Many methods of numerical integration (i.e., calculating an approximate solution to a differential equation) exist and are widely used in commercial and other software. Key to deriving accurate simulation results from a developed model is the selection of an appropriate numerical method. Typically, commercial software products recommend the appropriate method and the set of corresponding configuration parameters (i.e., solver settings) based on the type of simulation problem. For example, for detailed EPS simulation studies MATLAB® Simulink® recommends a variable-step, two-stage, Runge-Kutta based method "ode23tb" suitable for stiff systems with relative tolerance 1×10^{-4} .

CAUSAL MODELING: This modeling approach assumes that a system of interest can be decomposed into block-diagram form with causal interactions between the sub-models expressed in explicit form:

$$\begin{aligned}\frac{dX}{dt} &= f(X, U) \\ Y &= g(X, U)\end{aligned}\tag{Eq. 1}$$

where U is input, Y is output and X is the system state variable vectors. Hence, in the causal approach the goal is to express the system output Y explicitly as a variable that depends on U and X .