



AEROSPACE RECOMMENDED PRACTICE

ARP7094™

Issued

2025-02

Recommended Practice for Using Modeling and Simulation
for Certification of Aircraft, Products, and Systems

RATIONALE

This SAE Aerospace Recommended Practice (ARP) establishes a process for using modeling and simulation (M&S) as a method of compliance for meeting regulatory requirements that have been traditionally demonstrated through analysis, ground testing, and flight testing. While M&S has seen limited use for certification in the past, the recent introduction of innovative new aircraft and systems, which use highly complex technologies that are difficult, or even impossible, to test fully, necessitates a much more rigorous process for their use.

1. INTRODUCTION

1.1 Scope

The scope of this ARP is as follows:

- Use of M&S for type certification of the Advanced Air Mobility (AAM) aircraft, product, or system. However, this does not preclude this ARP being used for certification of other aircraft types and associated products and systems.
- This ARP is not applicable to flight simulation training device (FSTD) qualifications or pilot certification. If a qualified FSTD is proposed for aircraft, product, or system certification, it must demonstrate sufficient M&S substantiation to meet the related requirement.
- Structural design and modeling are not addressed by this document.
- EMI/EMC certification is not addressed by this document.

1.2 Background

The SAE International G-35 Modeling, Simulation, and Training for Emerging Aviation Technologies and Concepts Committee brings together experts in manufacturing, design, and operations with regulators and academia to develop consensus-based standards to address the needs of the burgeoning AAM industry. These emerging aircraft designs require significant changes to the certification process for the aircraft and its associated systems and for supporting training methods, personnel, and environment. The use of M&S for certification credit is one part of the certification process that requires this sort of change.

Historically, the certification process has seen use of M&S at only the highest system levels, primarily to re-create failures seen in real life. This use of M&S can increase the safety of aviation systems by providing a safe mechanism to test corner cases that would otherwise be too dangerous to fly. When this technique has been proposed for this purpose, acceptance of the model or simulation by the certification authority has been somewhat arbitrary without a standard for evaluation for acceptance. Expansion of M&S to further testing, including nominal cases, has therefore been slow.

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2025 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, or used for text and data mining, AI training, or similar technologies, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE ARP7094

For more information on this standard, visit
<https://www.sae.org/standards/content/ARP7094/>

Documents

Standard, visit Sharing Hub

However, M&S has supported type certification in aviation for decades, although they have rarely been used as primary methods of compliance despite their proven reliability. Current advances in complex systems, particularly tightly coupled flight controls and power plants, are increasingly common in general aviation, and the numerous interactions among such systems make physical test of all potential cases impractical. The use of validated models and simulations allows a much wider range of tests and enables early assessment of flight performance and characteristics as well as the performance of the aircraft, power plants, propulsors, and systems. M&S is now recognized as a standard method for certification. This recommended practice was written to establish a process by which M&S can be incorporated into the path to certification, avoiding the arbitrary nature of the historical process and encouraging more widespread use. While this recommended practice is intended to address new and emerging aircraft designs, it is also applicable to conventional aircraft that incorporate new technologies and capabilities.

TABLE OF CONTENTS

1.	INTRODUCTION.....	1
1.1	Scope	1
1.2	Background	1
2.	REFERENCES.....	4
2.1	Applicable Documents	4
2.1.1	SAE Publications.....	4
2.1.2	Code of Federal Regulations (CFR) Publications	4
2.1.3	EASA Publications	4
2.1.4	ICAO Publications	4
2.1.5	RAeS Publications	4
2.1.6	Transport Canada Publications.....	4
2.2	Related Publications	5
2.2.1	SAE Publications.....	5
2.2.2	Code of Federal Regulations (CFR) Publications	5
2.2.3	EASA Publications	5
2.2.4	FAA Publications	6
2.2.5	IEEE Publications.....	6
2.2.6	NATO Publications	6
2.2.7	RTCA Publications	6
2.2.8	Transport Canada Publications.....	6
2.3	Abbreviations	7
2.4	Definitions	8
3.	CERTIFICATION PROCESS USING SIMULATION	10
3.1	Overview	10
3.2	Simulation for Credit Review (SCR) Process.....	10
4.	SIMULATION PLAN	11
4.1	Overview	11
4.1.1	Simulation Plan Objective 1: Descriptions	11
4.1.2	Simulation Plan Objective 2: Applicable Regulations	12
4.1.3	Simulation Plan Objective 3: Simulation Environment.....	13
4.1.4	Simulation Plan Objective 4: Scalable Simulations	13
4.1.5	Simulation Plan Objective 5: Configuration Management	13
4.1.6	Simulation Plan Objective 6: Design and Reference Data	14
4.1.7	Simulation Plan Objective 7: Limitations of the Simulation.....	15
4.1.8	Simulation Plan Objective 8: Testing Methods	16
4.1.9	Simulation Plan Objective 9: Test Witnessing Plan	16
4.1.10	Simulation Plan Objective 10: Test Scopes and Regulation Mapping.....	16
4.2	System Testing	16
4.2.1	Scope	16
4.2.2	Applicable Regulations for System Testing	16
4.2.3	Proposed Simulations for System Testing	17
4.2.4	Scalable Simulations for System Testing.....	17
4.2.5	Design and Reference Data for System Testing	17

4.2.6	Limitations of the Simulation for System Testing	17
4.2.7	Testing Methods for System Testing	17
4.2.8	Witnessing for System Testing	17
4.3	Human Factors Testing	17
4.3.1	Scope	17
4.3.2	Applicable Regulations for Human Factors Testing	18
4.3.3	Proposed Simulations for Human Factors Testing	18
4.3.4	Scalable Simulations for Human Factors Testing	18
4.3.5	Design and Reference Data for Human Factors Testing	18
4.3.6	Limitations of the Simulation for Human Factors Testing	18
4.3.7	Testing Methods for Human Factors Testing	18
4.3.8	Witnessing for Human Factors Testing	18
4.4	Flight Testing	19
4.4.1	Scope	19
4.4.2	Applicable Regulations for Flight Testing	19
4.4.3	Proposed Simulations for Flight Testing	19
4.4.4	Scalable Simulations for Flight Testing	19
4.4.5	Design and Reference Data for Flight Testing	19
4.4.6	Limitations of the Simulation for Flight Testing	19
4.4.7	Testing Methods for Flight Testing	19
4.4.8	Witnessing for Flight Testing	20
5.	SIMULATION VALIDATION PLAN AND SIMULATION VALIDATION REPORT	20
5.2	Simulation Validation Plan	20
5.2.1	Simulation Validation Objective 1: Model Description	20
5.2.2	Simulation Validation Objective 2: Validation Test	21
5.2.3	Simulation Validation Objective 3: Validation Criteria and Tolerances	21
5.2.4	Simulation Validation Objective 4: Reference Data Collection Criteria	22
5.3	Simulation Validation Objective 5: Simulation Validation Report	23
6.	SIMULATION TEST PLAN AND EXECUTION	23
6.1	Overview	23
6.2	Simulation Test Plan	24
6.2.1	Introduction/Purpose	24
6.2.2	System Description	24
6.2.3	Simulation Test Plan Objective 1: Prerequisites	24
6.2.4	Simulation Test Plan Objective 2: Simulation Environment	24
6.2.5	Simulation Test Plan Objective 3: Configuration	24
6.2.6	Simulation Test Plan Objective 4: Test Personnel	24
6.2.7	Simulation Test Plan Objective 5: Instrumentation	24
6.2.8	Simulation Test Plan Objective 6: Test Description	25
6.2.9	Simulation Test Plan Objective 7: Safety	25
6.2.10	Simulation Test Plan Objective 8: Data Analysis and Reporting	25
6.2.11	References	25
7.	SIMULATION TEST REPORTS	26
7.1	Overview	26
7.2	Simulation Test Report Objective 1: Documentation	26
7.3	Approval	26
8.	NOTES	27
8.1	Revision Indicator	27
APPENDIX A	TOLERANCES	28
APPENDIX B	MODEL FIDELITY FOR TESTING	31

Figure 1 Optional M&S certification path

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.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARP4754B Guidelines for Development of Civil Aircraft and Systems

2.1.2 Code of Federal Regulations (CFR) Publications

Available from United States Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

14 CFR Part 60 Flight Simulation Training Device Initial and Continuing Qualification and Use

2.1.3 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

CS-FSTD(A) Aeroplane Flight Simulation Training Devices

CS-FSTD(H) Helicopter Flight Simulation Training Devices

2.1.4 ICAO Publications

Available from International Civil Aviation Organization, 999 University Street, Montreal, Quebec H3C 5H7, Canada, Tel: +1 514-954-8219, <http://www.icao.int/>.

ICAO 9625 Manual of Criteria for the Qualification of Flight Simulation Training Devices (Volume 1 - Aeroplanes, Fourth Edition, 2015)

2.1.5 RAeS Publications

Available from the Royal Aeronautical Society, Tel: +44 (0) 20 7670 4352, <https://www.aerosociety.com/>.

Aeroplane Flight Simulation Training Device Evaluation Handbook, Volume 1

2.1.6 Transport Canada Publications

Available from Transport Canada, Tower C, Place de Ville, 330 Sparks Street Ottawa, Ontario K1A 0N5, Tel: 1-800-305-2059, www.tc.gc.ca.

TP 9685E Aeroplane and Rotorcraft Simulator Manual

2.2 Related Publications

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

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

ARINC 610C Guidance for Design of Aircraft Equipment and Software for Use in Training Devices

2.2.2 Code of Federal Regulations (CFR) Publications

Available from United States Government Publishing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

- 14 CFR Part 21 Certification Procedures for Products and Articles
- 14 CFR Part 23 Airworthiness Standards: Normal Category Airplanes
- 14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes (FAA)
- 14 CFR Part 27 Airworthiness Standards: Normal Category Rotorcraft (FAA)
- 14 CFR Part 29 Airworthiness Standards: Transport Category Rotorcraft (FAA)
- 14 CFR Part 33 Airworthiness Standards: Aircraft Engines
- 14 CFR Part 35 Airworthiness Standards: Propellers

2.2.3 EASA Publications

Available from European Union Aviation Safety Agency, Konrad-Adenauer-Ufer 3, D-50668 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

EC Reg 748/2012 Annex I - Part 21

- CS-23 Normal, Utility, Aerobatic and Commuter Airplanes
- CS-25 Large Airplanes
- CS-27 Small Rotorcraft
- CS-29 Large Rotorcraft
- CS-E Engines
- CS-P Propellers
- SC-VTOL Special Condition for VTOL and Means of Compliance

2.2.4 FAA Publications

Available from Federal Aviation Administration, 800 Independence Avenue, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

8110.4C FAA Order, Type Certification, with Change 7

AC 21.17-4 Type Certification - Powered-lift

AC 23.2010-1 FAA Accepted Means of Compliance Process for 14 CFR Part 23

2.2.5 IEEE Publications

Available from IEEE Operations Center, 445 and 501 Hoes Lane, Piscataway, NJ 08854-4141, Tel: 732-981-0060, www.ieee.org.

An Integrated Modeling, Simulation and Analysis Framework for Engineering Complex Systems

2.2.6 NATO Publications

Copies of these documents are available online at <https://www.sto.nato.int/publications/>.

STO-TR-AVT-296-UU Rotorcraft Flight Simulation Model Fidelity Improvement and Assessment by the North Atlantic Treaty Organization Science and Technology Organization (NATO S&TO)

2.2.7 RTCA Publications

Available from RTCA, Inc., 1150 18th Street, NW, Suite 910, Washington, DC 20036, Tel: 202-833-9339, www.rtca.org.

DO-178C/ED-12C Software Considerations in Airborne Systems and Equipment Certification

DO-330/ED-215 Software tool qualification considerations.

DO-331/ED-218 Model-Based Development and Verification Supplement to DO-178C and DO-278A

2.2.8 Transport Canada Publications

Available from Transport Canada, Tower C, Place de Ville, 330 Sparks Street Ottawa, Ontario K1A 0N5, Tel: 1-800-305-2059, www.tc.gc.ca.

AWM 523N Normal Category Aeroplanes

AWM 525 Transport Category Aeroplanes

AWM 527 Normal Category Rotorcraft

AWM 529 Transport Category Rotorcraft

AWM-533 Aircraft Engines

AWM-535 Propellers

2.3 Abbreviations

The following abbreviations are provided for information purposes only.

AAM	advanced air mobility
AC	Advisory Circular (FAA)
AFHA	aircraft functional hazard assessment
AI	artificial intelligence
ANAC	Agência Nacional de Aviação Civil (Brazil)
AR	augmented reality
ARP	Aerospace Recommended Practice (SAE)
ARAC	Aviation Rulemaking Advisory Committee
AS	Aerospace Standard (SAE)
ASTM	ASTM International
AWM	Airworthiness Manual (TCAN)
CAA	Civil Aviation Authority (United Kingdom)
CFR	Code of Federal Regulations (FAA)
CS	Certification Specification (EASA)
EASA	European Union Aviation Safety Agency
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EUROCAE	European Organisation for Civil Aviation Equipment
eVTOL	electric vertical takeoff and landing
FAA	Federal Aviation Administration
FSTD	flight simulation training device
HF	human factors
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council on Systems Engineering
M&S	modeling and simulation
MBD	model-based definition
MR	mixed reality

NATO	North Atlantic Treaty Organization
PSCP	project specific certification plan
RAeS	Royal Aeronautical Society
RTCA	Radio Technical Commission for Aeronautics
S&TO	Science & Technology Organization (NATO)
SAE	SAE International
SC	supplemental certification (EASA)
SCR	simulation for credit review
SME	subject matter expert
STOL	short takeoff and landing
TC	type certification
TCAN	Transport Canada
UAM	urban air mobility
VR	virtual reality
VTOL	vertical takeoff and landing
XR	extended reality

2.4 Definitions

ADVANCED AIR MOBILITY (AAM): Operations with novel aircraft designs that do not fall into a traditional category, and that have vertical takeoff and landing capabilities and distributed propulsion features, may be operated in unmanned/uncrewed configurations that are conceived to offer a new air mobility of people and cargo in congested (urban) areas based on an integrated air and ground-based infrastructure. AAM describes a diverse array of aircraft types (such as manned and unmanned) whose designs are enabled by ongoing innovations, particularly in the areas of hybrid and electrification of propulsion systems, energy storage, lightweight materials, digitalization, and automation. These innovations have made possible an array of novel designs spanning multi-rotor, tilt wing, tilt-rotor, and powered wing and offer short takeoff and landing (STOL) through to vertical takeoff and landing (VTOL) capabilities.

CERTIFICATION AUTHORITY: Organization or person responsible for granting approval in accordance with applicable regulations.

CONFIGURATION CONTROL: The method of controlling, approving, and tracking changes to a product's deliverables and processes.

CONFORMITY: Aircraft that conforms to its type design and is configured/bridged to the approved program and operations.

ELECTRIC VERTICAL TAKEOFF AND LANDING (eVTOL): eVTOL aircraft may be powered by hybrid electric systems, batteries, or potentially hydrogen fuel cells. An eVTOL aircraft uses electric power to hover, take off, and land vertically. This technology came about thanks to major advances in electric propulsion and the growing need for new vehicles for urban air mobility.

EMULATION: Mimics the output behavior to match an existing target. The internal state of the emulation mechanism does not have to accurately reflect the internal state of the target that it is emulating.

FLIGHT TESTING: Testing where the intent is to establish the aircraft flight characteristics by a qualified test pilot and that is used as a truth source to validate the M&S.

HARDWARE-IN-THE-LOOP: A testing methodology used to simulate the behavior of complex systems. It involves integrating actual hardware components with simulation models to test and validate the performance and functionality of control systems in a controlled environment.

HUMAN-IN-THE-LOOP: Human is in direct control of the systems.

HUMAN-ON-THE-LOOP: Human has supervisory control of the systems. Human actively monitors the systems and can take full control when required or desired.

HUMAN-OUT-OF-THE-LOOP: Human delegates all authority to the system once the execution of the function is enabled. Automated processes are in control of the system and have the authority to perform actions without the human having awareness of the actions being taken.

HUMAN-OVER-THE-LOOP: Human has supervisory control of the systems. Human passively monitors the systems and is informed by automation if, and what, action is required. Human is engaged by the automation either for exceptions that are not reconcilable or as part of rule set escalation.

MEANS OF COMPLIANCE: A detailed design standard that, if met, accomplishes the safety intent of the regulation, is used by an applicant to show compliance with the applicable airworthiness criteria, and is accepted by the Certification Authority. A means of compliance is one method, but not the only method, to show compliance with a regulatory requirement. For this document, a specific description of HOW the models and simulations are used would constitute one way to establish a means of compliance for them.

METHOD OF COMPLIANCE: A description of how compliance will be shown (e.g., ground test, flight test, analysis, similarity, etc.). For the purposes of this document, the use of models and simulations (or a formal name appropriately established) would be a method of compliance. The description of the method of compliance should be sufficient to determine that all necessary compliance-related data will be collected and all findings can be made.

MODEL: A mathematical, physical, or conceptual representation of a given set of aspects of a system/function/item that is used for its analysis, implementation, simulation, or code generation and that has unambiguous, well-defined syntax and semantics.

MODELING: The process of creating a model.

SCALABLE SIMULATION: The ability for a simulation to be adapted for use in environments of variable complexity.

SIMULATED: A functional representation of something, such as a physical system.

SIMULATION: A simulation is the imitation of the operation of a real-world process or system over time. Simulations require the use of models; the model represents the key characteristics or behaviors of the selected system or process, whereas the simulation represents the evolution of the model over time. Computers are often used to execute the simulation.

TYPE CERTIFICATION: The approval of the design of the aircraft and all component parts. It signifies the design is in compliance with the applicable standards.

VALIDATION: The process of determining the degree to which a model or a simulation is an accurate representation of the real world from the perspective of the intended uses of the M&S.

VERIFICATION: The process of determining that an M&S implementation accurately represents the intended description and function.

3. CERTIFICATION PROCESS USING SIMULATION

3.1 Overview

Figure 1 shows an optional certification process that may be used to include the use of M&S. Further details are provided in Sections 4 through 7.

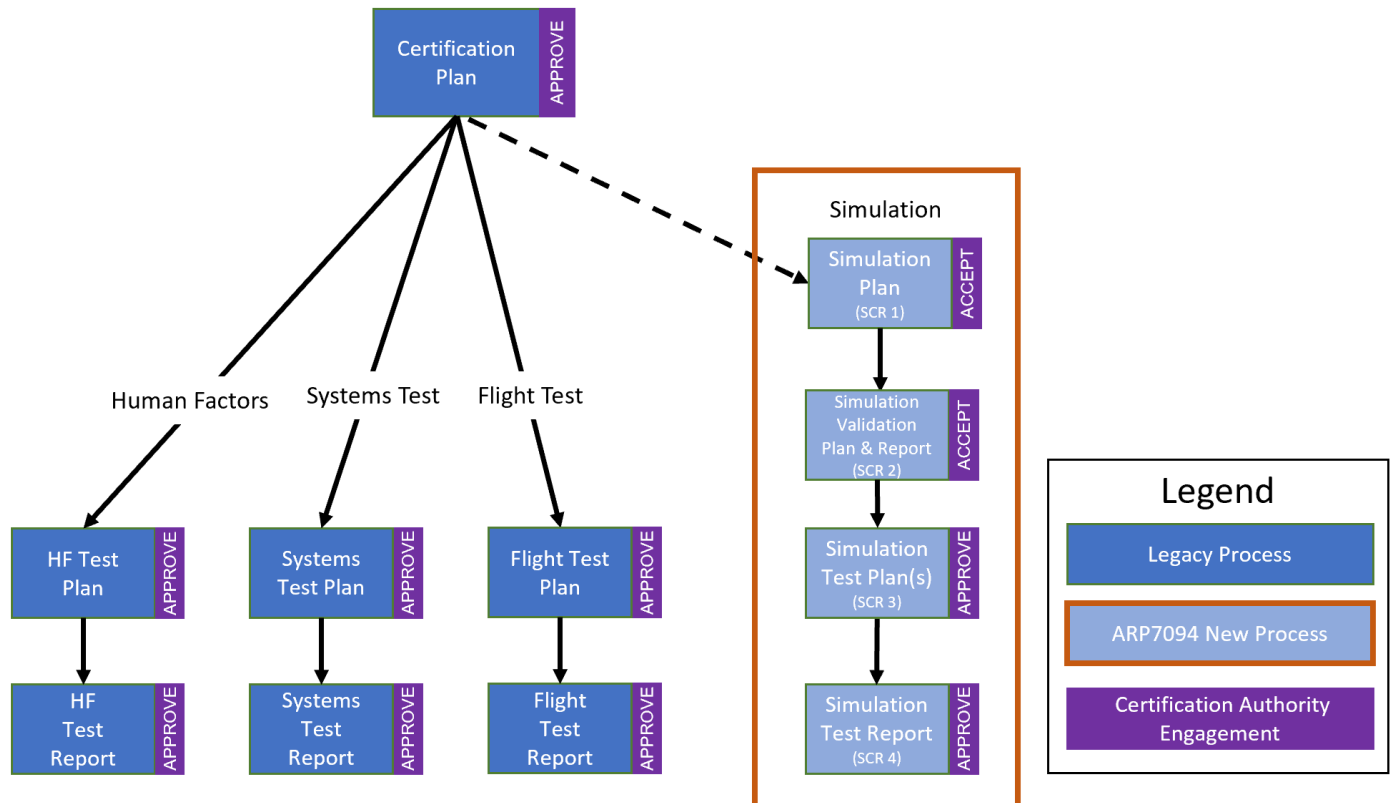


Figure 1 - Optional M&S certification path

3.2 Simulation for Credit Review (SCR) Process

A review process ensures close coordination between the applicant and Certification Authority during the development and eventual certification. The certification process using simulation should utilize the Simulation for Credit Review (SCR) process to ensure the same close coordination between the applicant and the Certification Authority. The SCR should include the following reviews to provide confidence in the simulation for the end product (simulation for a system, systems, or integrated systems up to and including the aircraft system as a whole) to be used in lieu of extensive certification flight or system testing.

SCR1: A review should be conducted when the Simulation Plan is ready to be submitted to the Certification Authority (see Section 4). The Simulation Plan can be a stand-alone document or included in the Certification Plan, or equivalent.

SCR2: A review should be conducted when the Simulation Validation Plan and Simulation Validation Report are ready to be submitted to the Certification Authority (see Section 5).

SCR3: A review should be conducted when the Simulation Test Plan is ready to be submitted to the Certification Authority or delegated representative (see Section 6).

SCR4: A final review should be conducted when the Simulation Test Report is ready to be submitted to the Certification Authority or delegated representative (see Section 7).

4. SIMULATION PLAN

4.1 Overview

The Simulation Plan describes the intent and scope of the simulation.

This document describes how M&S should be used for certification. It is advised that if this ARP is to be used, the Simulation Plan is described for the applicant's project as a method of compliance.

The Simulation Plan should fulfill the Simulation Plan objectives described throughout this section.

The Simulation Plan should contain the following:

- Descriptions of the systems, components, features, etc., that compliance is being shown for
- Applicable regulations
- Proposed simulations
- Scalable simulations
- Simulation environment
- Configuration management plan for simulations: repositories, change management
- Reference/design data used to create and verify the simulation
- Limitations of the simulation
- Testing methods
- Test witnessing according to the Certification Authority test witnessing guidelines

It should be noted that if any of the objectives change, the Simulation Plan will have to be updated.

4.1.1 Simulation Plan Objective 1: Descriptions

Describe the aircraft systems and features for which the simulation will be used to show compliance.